Report of the Spatial Utilization of Benthic Habitats by Demersal Fish on the Scotian Shelf Synthesis Meeting 2007

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REPORT OF THE SPATIAL UTILIZATION OF BENTHIC HABITATS BY DEMERSAL FISH ON THE SCOTIAN SHELF SYNTHESIS MEETING 2007

by

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ABSTRACT

Anderson, J.T., and Gordon, D.C., Jr. 2007. Project review of spatial utilization of benthic habitats by demersal fish on the Scotian Shelf. Can. Tech. Rep. Fish. Aquat. Sci. 2770: vii + 82 p.

This report is based on presentations made during a scientific meeting held March 27-29, 2007 in the Main Auditorium of the Bedford Institute of Oceanography. The project was first conceived in the autumn of 2000 with a pilot project being conducted in 2001 on the Scotian Shelf. Funding and support for the project was based on the strategic science programs of Fisheries and Oceans Canada. Directed field work was carried out in the autumns of 2002, 2003 and 2005. The scientific meeting was a major synthesis of progress to date and advances in our understanding of what constitutes demersal habitats for juvenile haddock and Atlantic cod on the Scotian Shelf, Canada based on this research program. Four external reviewers participated in the scientific meeting to provide a level of peer review and suggestions on future work. All of the scientific presentations are available on-line:
ftp://starfish.mar.dfo-mpo.gc.ca/pub/ocean/Fish_Habitat

The intent of this report is to complement these presentations with brief summaries of the scientific activities, results, interpretations and planned future directions. Fourteen different authors contributed to this report and a total of 66 individuals participated in the meeting (Appendix A). The meeting agenda is provided in Appendix B.

Activities carried out by the different research teams included analyses of historical data (Anderson et al. 2005), summaries of what constitutes fish habitat based on published studies (Linehan 2002; Gilkinson and Anderson 2007; Gregory et al. 2007), comparison of acoustic seabed classification systems used in the study (Courtney et al. 2005), comparison of different fish capture systems (Anderson et al. 2007), review of our existing understanding of surficial geology and process (Fader 2007a) and management of geo-referenced, multi-layered databases (Clement 2007). Directed studies developed new observations on surficial geology (Fader 2007b), acoustic measurements of physical seabed habitats (Anderson et al. 2007; Courtney 2007), fish communities associated with the study areas (Dalley et al. 2007), haddock and Atlantic cod distributions across multiple spatial scales based on acoustic observations (Anderson et al. 2007), epifaunal communities on Western Bank (Gilkinson 2007) and dietary links of juvenile haddock and Atlantic cod (Kenchington 2007). Cross-project syntheses has only recently begun with the measures of habitat suitability criteria for juvenile haddock and Atlantic cod in relation to surficial sediments (Ollerhead and Anderson 2007) and a summary of our increased understanding based on progress to date (Anderson and Gordon 2007a). A summary of anticipated future directions is based primarily on analyses and interpretations of the existing data but also outlines directed new data requirements (Anderson and Gordon 2007b). The external reviewers each provided a summary of the project strengths and weakness (Boisclair 2007; Brown 2007; Collie 2007; Link 2007) and their presentations are also available

on-line. At this point a world class geo-referenced database has been developed that will allow researchers to address the original project objectives (Gordon 2007). Synthesis of the multi-disciplinary data will require ongoing collaboration among researchers from the different institutions and scientific disciplines. Application of multivariate analyses techniques, predictive model development, habitat definition and model testing remain as identifiable challenges for future work.

RÉSUMÉ

Anderson, J.T., and Gordon, D.C., Jr. 2007. Project review of spatial utilization of benthic habitats by demersal fish on the Scotian Shelf. Can. Tech. Rep. Fish. Aquat. Sci. 2770: vii + 82 p.

Le présent rapport est fondé sur les exposés présentés à une réunion scientifique qui a eu lieu du 27 au 29 mars 2007 dans le grand auditorium de l'Institut océanographique de Bedford. Cette réunion portait sur un projet conçu en automne 2000 et entrepris d'abord comme projet pilote sur le plateau néo-écossais en 2001. Le projet en question a été financé et appuyé dans le cadre du programme du Fonds stratégique des sciences de Pêches et Océans Canada. Les travaux dirigés sur le terrain ont été effectués durant l'automne de 2002, 2003 et 2005. La réunion scientifique avait pour but de procéder à une vaste synthèse des progrès réalisés jusqu'ici et de l'enrichissement connexe de nos connaissances sur ce qui constitue les habitats démersaux des aiglefins et des morues juvéniles sur le plateau néo-écossais. Quatre examinateurs externes y assistaient en vue d'assurer une forme d'examen par les pairs et de faire des suggestions sur les futurs travaux. Tous les exposés scientifiques peuvent être consultés en direct dans le site suivant : ftp://starfish.mar.dfo-mpo.gc.ca/pub/ocean/Fish_Habitat.

Le rapport présenté ici vise à compléter les exposés susmentionnés par de brefs résumés des activités, résultats et interprétations scientifiques, ainsi que par un aperçu des orientations futures. Quatorze auteurs ont contribué à la rédaction du rapport et 66 personnes ont participé à la réunion (annexe A). L'ordre du jour de cette dernière figure à l'annexe B.

Les activités entreprises par les différentes équipes scientifiques comprenaient des analyses des données historiques (Anderson et al. 2005), des résumés sur ce qui constitue l'habitat du poisson d'après des études publiées (Linehan 2002; Gilkinson and Anderson 2007; Gregory et al. 2007), une comparaison des systèmes de classification acoustique du plancher océanique utilisés dans l'étude (Courtney et al. 2005), une comparaison des divers systèmes de capture du poisson (Anderson et al. 2007) et un examen de nos connaissances de la géologie et des processus superficiels (Fader 2007a) ainsi que de la gestion de bases de données multicouches géoréférencées (Clement 2007). Les études dirigées ont débouché sur de nouvelles observations portant sur les éléments suivants : la géologie superficielle (Fader 2007b), les mesures

acoustiques des habitats du fond océanique (Anderson et al. 2007; Courtney 2007), les communautés de poissons associées aux zones étudiées (Dalley et al. 2007), la répartition de l'aiglefin et de la morue à de multiples échelles spatiales d'après des observations acoustiques (Anderson et al. 2007), les communautés épifauniques du banc Western (Gilkinson 2007) et les liens alimentaires entre l'aiglefin et la morue au stade juvénile (Kenchington 2007). Les synthèses croisées du projet n'ont commencé que dernièrement, par des mesures des critères de conformité de l'habitat aux besoins des aiglefins et morues juvéniles pour ce qui est des sédiments de surface (Ollerhead and Anderson 2007) et par un aperçu de l'enrichissement de nos connaissances en fonction des progrès réalisés à ce jour (Anderson and Gordon 2007a). Un résumé des orientations prévues pour l'avenir est fondé principalement sur les analyses et interprétations des données existantes, mais il fait aussi ressortir les besoins en matière de nouvelles données (Anderson and Gordon 2007b). Chacun des examinateurs externes a présenté un aperçu des points forts et des points faibles du projet (Boisclair 2007; Brown 2007; Collie 2007; Link 2007), qui est aussi disponible en ligne. Jusqu'ici, on a élaboré une base de données géoréférencées de calibre mondial, qui sera utile aux scientifiques pour atteindre les objectifs initiaux du projet (Gordon 2007). La synthèse des données multidisciplinaires nécessitera une collaboration continue entre les chercheurs des diverses institutions et disciplines scientifiques. L'application de techniques d'analyse à variables multiples, l'élaboration d'un modèle prévisionnel, la définition de l'habitat et la mise à l'épreuve du modèle sont autant de sujets d'étude pour l'avenir.

PROJECT OVERVIEW

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This project began in 2000 and represents a collaborative effort between the Northwest Atlantic Fisheries Centre (NAFC) in St. John's, Newfoundland and Labrador (Fisheries and Oceans Canada - DFO) and the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia (DFO and Natural Resources Canada–NRCan). A large team of engineers, geologists, fisheries ecologists, benthic ecologists and data managers participated. Team members had previously been working on various seabed habitat studies in Atlantic Canada including surficial geology mapping, inshore juvenile fish habitat, impacts of mobile fishing gear, impacts of offshore drilling wastes, deepwater corals, and habitat mapping. They had developed considerable experience in studying seabed habitat and were anxious to apply this expertise to new priority questions.

A top priority for DFO is to study, conserve and protect aquatic ecosystems, including seabed habitat. Seabed habitat plays a critical role in the life cycles of demersal fish, especially juveniles, but the details are poorly known. What constitutes preferred seabed habitat is poorly understood, especially at small spatial scales. Ecosystem management of fisheries requires knowledge of what constitutes preferred habitat for individual species, its spatial distribution, and its sensitivity to human disturbance. After considerable discussion, it was decided to design a new research project to address the following questions:

- What is the preferred seabed habitat for demersal fish, with focus on juvenile haddock?
- What is the relative importance of physical and biological attributes?
- What are the best methods for measuring preferred seabed habitat and are there suitable acoustic proxies?
- At what spatial scales should preferred habitat be measured?
- Where is preferred seabed habitat for juvenile haddock located on the Scotian Shelf?

The Scotian Shelf was selected as the study site because of its nearness to BIO, importance to commercial fisheries, abundant scientific information, site of the Eastern Scotian Shelf Integrated Management (ESSIM) project, and the presence of a large (~13,000 km^2) year-round closed area created in 1987 to protect juvenile haddock. Haddock was selected as the prime species of interest because of its numerical dominance in the area but data were also collected for other species, in particular Atlantic cod.

Specific study areas were selected using the DFO summer groundfish trawl survey data base (1970-2001). Paired sites were selected on Emerald, Western and Sable Island Banks in areas with the highest and lowest probabilities of encountering juvenile haddock (Anderson et al. 2005, Fig. 1). Study areas were defined as 10 x 10 km areas. There were significant differences in depth and bottom temperature between sites as well as differences in bottom current stress and oxygen saturation. However, all six sites were on Sable Island Sand and Gravel which contains a wide range of sediment clasts such as sand, pebble, cobble, and boulder (see Fader 2007).

The field program was designed to explore differences in seabed habitat between the six sites with different fish abundances. The following data sets were collected in late September and early October over a four year period at all six sites unless otherwise noted:

- Seabed habitat
    - Multibeam (2005) (only the two sites on Western and Sable Island preferred site)
    - Sidescan sonar (2002, 2003, 2005)
    - Biosonics DT digital, fully calibrated echosounder (2002, 2003, 2005)
    - Video and photographic imagery with Towcam (2002, 2003, 2005)
    - Geological properties of sediments (2002)
    - Bottom temperature (2002, 2003, 2005)
- Fish (day/night sampling to explore diurnal behaviour)
    - Campelen trawl sets, including stomach contents (2002, 2005)
    - Biosonics DT calibrated echosounder (2002, 2003, 2005)
    - Video imagery with Towcam (2002, 2003, 2005)
- Benthic communities
    - Photographic imagery of epibenthos with Towcam (2002, 2003, 2005)
    - Videograb samples of macrofauna from specific habitats (2003, 2005)
    - Stomach contents of fish (2002, 2005)

All data were georeferenced to within a few meters and different layers can be compared and integrated in a Geographic Information System (GIS) environment.

Seabed surveys were done over two spatial scales (Fig. 2). Acoustic surveys using the BioSonics DT were run along north-south and east-west lines at 800 m spacing over the entire 10 x 10 km study areas. Sidescan surveys were also run over about half these lines. Multibeam surveys (only Western preferred and non-preferred and Sable Island preferred) were also run over the entire study areas. On the basis of the initial results in 2002, a 1 x 5 km detailed study area was selected within each study area. The intent was to select an area which included the full range of habitat types found within the larger area. These detailed study areas were intensively surveyed using all the survey tools: sidescan sonar, Biosonics DT, Towcam, Videograb, IKU grab, and Campelen trawl. In addition, two 10 km lines were surveyed in each study area in 2005 but these data were not presented at the meeting.

The sampling design allows comparisons to be made over different spatial scales. At the largest scale, it is possible to compare properties between Emerald, Western and Sable Island Bank. Within banks, it is possible to compare properties between the two 10 x 10 km study sites which were selected to encompass areas with the highest and lowest probabilities of finding juvenile fish. Within our study areas, it is possible to compare properties at scales down to just a few meters.

Project management was shared between BIO (D. Gordon) and NAFC (J. Anderson). A research team was assembled with the necessary expertise. Semi-annual workshops involving all participants were held to review progress and make plans. The workshops rotated between BIO and NAFC. Communication was also facilitated by the fact that most of the team went to sea together for several weeks each year (except 2004). Major decisions were made by consensus of the entire team and well documented in a paper trail. Special attention was given to setting up a robust data management system. Periodic briefings were given to potential clients.

DFO funding was provided by the Environmental Science Strategic Research Fund (ESSRF), the Science Strategic Fund (SSF) and A-Base. NRCan funding was provided by A-Base. Many people, beyond the immediate study team, contributed to this project including DFO and NRCan managers, the Coast Guard for ship support, technical services, administrative support, and numerous colleagues and volunteers who provided advice and assisted in both the field and laboratory.

Not all data have been processed but progress in data analysis and interpretation is reported in the following presentations.

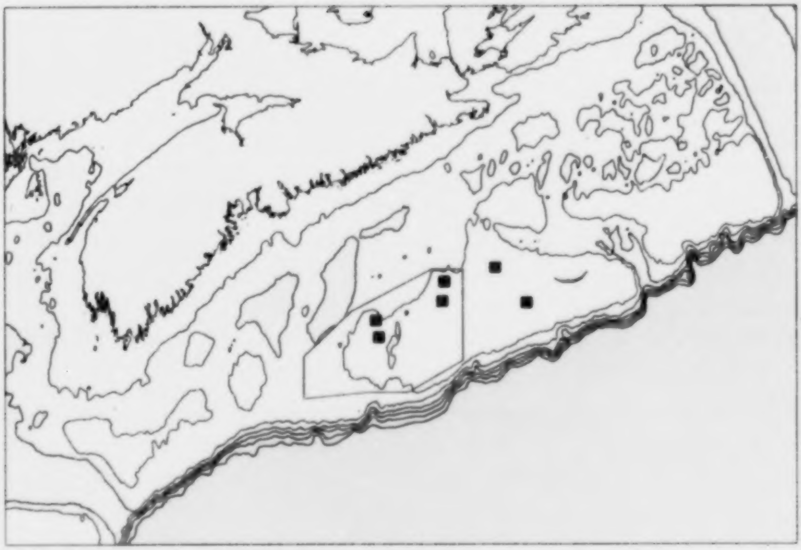


Figure 1. Map of the Scotian Shelf showing the location of the six paired study areas (10 x 10 km) on the Scotian Shelf. The red squares shows sites with the highest probabilities of finding juvenile haddock on each of the three banks while the blue squares shows sites with the lowest probabilities. The polygon marked in red is the haddock closed area.

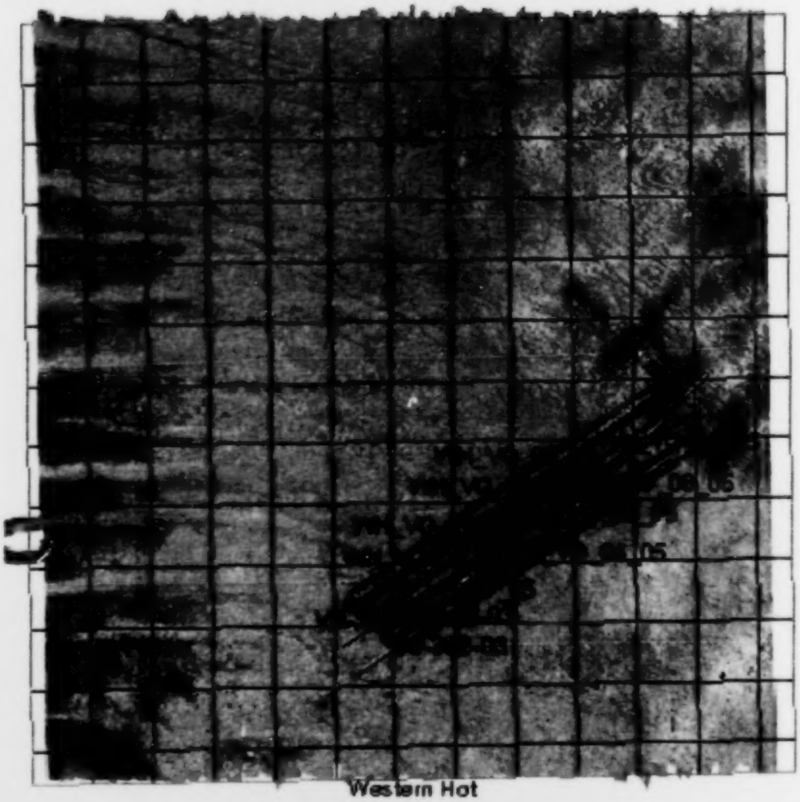
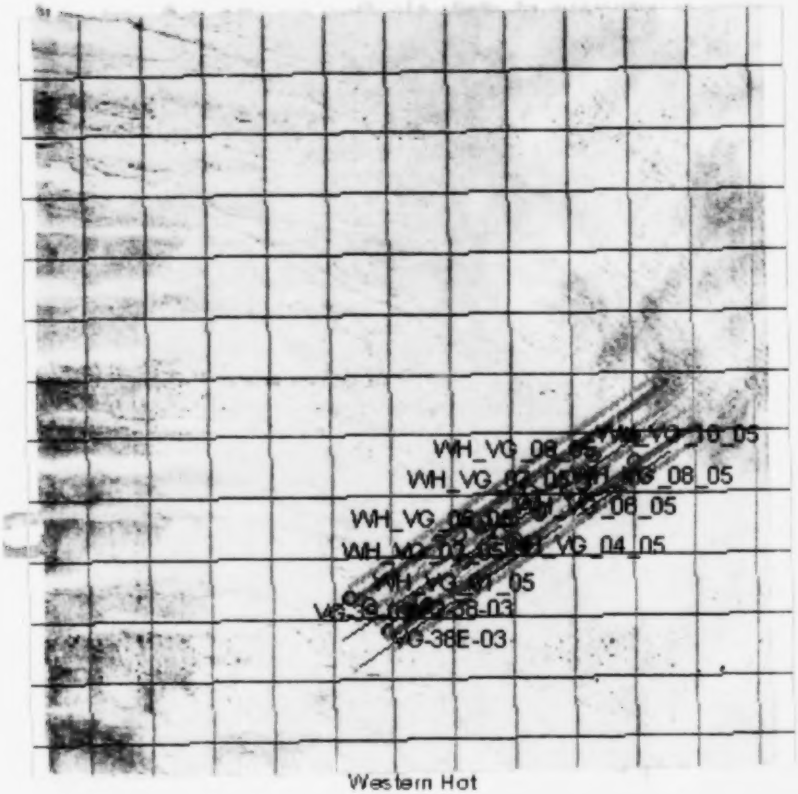


Figure 2. Map of survey design at the Western preferred study area (10 x 10 km). The horizontal (dark blue) lines and vertical (brown) red lines are 10 km in length and spaced 800 m apart. The diagonal (red, light blue) lines are 5 km in length and spaced 200 m apart. The labels refer to Videograb locations. The underlying bathymetric surface was generated from the multibeam data and is false colour shaded from shallow (red) to deep (blue).



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TRENDS IN TEMPERATE MARINE FISH HABITAT RESEARCH: DEFINING HABITAT BASED ON SCIENCE AND LEGISLATION

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The impetus for this review was a fundamental question that arose during the course of research carried out on the Scotian Shelf (eastern Canada) designed to identify important habitat for juvenile haddock (*Melanogramus aeglefinus*); what is fish habitat and how is it measured? The term "habitat" is one of the most widely used terms in ecology for which an understanding of its' meaning is typically assumed. The weak explanatory and predictive power of existing marine fish-habitat relationships is thought to arise from the application of easily measured or available habitat variables (e.g. depth) as opposed to relevant habitat variables that are independent. Both government legislation and policy definitions and science definitions were incorporated into the review since the former has become a driving force for fish habitat research. The primary objectives of the review were to identify: (i) variables used by researchers to delineate "fish habitat" and the rationale for their selection, (ii) differences in variable selection related to environment, life stage or taxon, (iii) relationships between fish abundance, growth or mortality and habitat variables, (iv) knowledge gaps in fish habitat research, (v) studies that explore functional relationships between fish and habitat, (vi) frequency of identification of essential fish habitat (EFH) or other synonymous terms. Lastly, we describe trends and directions for future marine fish habitat research.

A cross-section of recent marine fish habitat primary scientific literature was reviewed. In total, 70 publications from 19 journals were reviewed (1984-2004) while the majority of selected studies (80%) were published after 1996 in order to focus on research conducted after the introduction of EFH terminology. A filter was used in which only publications with habitat in their titles were selected to ensure that it was the author's intention to study habitat. Publications were selected by their title, ensuring that there was a marine setting and that it was a field study. The majority of references to habitat were in the context of 'habitat' *per se* or settlement or nursery habitat. Various combinations of biotic and abiotic variables were selected *a priori* by researchers in attempts to identify temporal and spatial relationships between fish and "habitat". For each paper, these variables (or descriptors) were scored as presence-absence. In order to compare selection of fish habitat descriptors between studies, multivariate analyses were performed on various study groupings including environmental setting (e.g. estuary, offshore), age of fish (juvenile, adult) and broad taxonomic category (e.g. Pleuronectiformes, non-Pleuronectiformes). Multivariate analyses were performed using PRIMER software (Clarke and Gorley, 2006). Non-metric multi-dimensional scaling ordination (nMDS) was performed on a Bray-Curtis similarity matrix of studies using presence-absence data for biotic and abiotic variables. The significance of ordinations

was tested using the analysis of similarities routine (ANOSIM). In cases where groupings of studies were significantly different, the underlying relationships behind these differences were determined using the similarity percentages routine (SIMPER). Studies were also scored (presence-absence) in terms of whether they addressed the objectives listed above.

In general, definitions of fish habitat found in government legislation/policy/guidelines tend to be variations on a theme and are "all encompassing". Studies carried out in estuarine environments were most prevalent (33%) followed by inshore (21%) and offshore environments (16%). Approximately 50% of the studies dealt exclusively with commercial species while 37% involved both commercial and non-commercial species. Overall, 49% of the studies focused on a single species followed by species assemblages (37%). Although 51% of the studies focused on juveniles (young-of-the-year and older juveniles) this increased to 75% when only studies that focused exclusively on flatfish were considered. Applying the National Marine Fisheries Service classification of EFH information, Level 2 data comprising fish abundance or density estimates dominated the studies (77%). Growth rate information (Level 3 data) was provided in 23% of the studies. None of the studies were based only on fish presence-absence data (Level 1), nor did they achieve the highest level of information comprising biological productivity (Level 4). A total of 36 environmental variables were used by researchers in attempts to delineate fish habitat. These were grouped into three broad categories: (1) physical, (2) biotic and (3) biogenic (inanimate structures of biological origin such as tubes, empty shells). Physical variables accounted for 78% of the total number of variables followed by biotic (14%) and biogenic (8%). Variables within these categories were ranked in terms of percent frequency of occurrence for all the studies. Temperature, salinity, depth and sediment type dominated the physical category. Vegetation and epifauna dominated the biotic category while "empty shells" was the most frequently recorded biogenic variable. The mean ($\pm$ SD) number of variables measured per study was 4.1 ($\pm$ 2.2). In all three environments (estuaries, inshore and offshore), physical variables dominated (average of 2.4-3.9 variables per study). The mean numbers of biogenic and biotic variables used per study were uniformly low in the three environments (0.2-0.8). Multi-dimensional scaling ordination (MDS) was performed on a sub-set of the 70 studies in order to determine the effect of environmental setting on variables selected for analysis. For this, studies were taken from the three most common environments: estuarine, inshore and offshore. Estuarine studies were weakly separated from inshore (ANOSIM R=0.22, P=0.004) and offshore (ANOSIM R=0.22, P=0.018) studies. Inshore and offshore studies were virtually inseparable (ANOSIM R=0.002, P=0.43). There was no significant separation of studies grouped by the broad taxonomic categories 'Pleuronectiformes' and 'non-Pleuronectiformes' (ANOSIM R= -0.087, p=0.949). A total of 64% of the studies provided rationale for *a priori* selection of habitat variables. In most cases, citation of previous research indicating the importance of these variables formed the basis for their selection. It is also noted that researchers in only 41% of the studies provided some form of definition or interpretation of fish habitat in the introduction, perhaps highlighting the implicit assumption by researchers of a fundamental understanding of the term 'habitat'.

A majority of the studies (89%) reported a significant relationship between fish abundance or growth rates and one or more of the selected habitat variables. The perceived importance of common variables, measured as the proportion of all 70 studies that included a given variable, were compared to the actual success of that variable in explaining fish abundance, growth or mortality. Temperature, salinity, depth and sediment type were perceived to be relatively important habitat variables with frequencies of occurrence >40%. Studies that included these variables had success rates ranging from 22% to 36%. Conversely, the variable 'structure' was included in only 6% of the studies; however, three of the four studies that included these variables reported a significant relationship with fish abundance or growth. Insight into functional relationships between fish and their habitat (e.g. significant habitat variables) was provided in 41% of the studies. While essential habitat was identified in just 7% of the studies, 16% described habitat as being either "important", "preferred", "highly dependent", "distinctive" or a "major requirement". Approximately half of the studies identified knowledge gaps or included suggestions for future research. Although in the current review the majority of studies identified a relationship between fish abundance or growth and one or more physical variables, the question remains whether a predominantly physical focus fully captures all the environmental features necessary to identify fish habitat, particularly essential or critical habitat.

Distributions of fish must be stationary in space over meaningful time periods (e.g. for specific life stages) prior to assigning a definition of what constitutes habitat. When fish distribute themselves in the same way over years to decades, then it is reasonable to assume areas of persistence represent areas of preferred habitats and, conversely, when fish avoid specific areas then these would represent non-preferred habitats. Assigning probabilities to observed distributions allows for an array of habitat qualities. In many cases, distributional fish data can be derived from long term observational data sets, such as research vessel surveys and also from traditional ecological knowledge (TEK). Any definition of fish habitat must include landscape features, in addition to local abiotic and biotic variables. To a large degree we do not yet know what these relevant spatial scales are. Experience with terrestrial systems tells us that to understand processes and make predictions within a scale we must sample at one spatial scale above and one spatial scale below the scale of interest. Habitat definitions must incorporate density dependent habitat selection in a predictable way. Therefore, we should strive to both develop and test predictions based on our definitions of preferred and non-preferred fish habitats. The degree to which fish habitat constitutes discrete areas with easily defined borders versus a gradient or cline from more preferred to less preferred should be a primary focus for future research. Advances in marine technologies are revolutionizing the way we look at life beneath the ocean surface. Foremost among these are acoustic technologies that measure the seabed surface at resolutions from centimeters to meters continuously at the scale of shelves and basins. Increasingly, optical technologies are being used to develop photographic mosaics from meters to kilometers across the seabed. Application of these emerging technologies should lead to meaningful progress in associating fish with

their habitats across multiple spatial scales that ultimately will lead to understanding at the scale of landscapes.

HABITAT ASSOCIATIONS AND STOCK STATUS OF HADDOCK AND ATLANTIC COD ON THE EASTERN SCOTIAN SHELF

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The historical distribution of haddock extends from Virginia to Labrador, where they were most abundant on offshore banks. The current distribution is truncated in the north and the south, with abundance being highest from Cape Cod to the Scotian Shelf. Spawning activity is temperature dependent, occurring January–August, generally showing a peak in April. Eggs are laid near the bottom over pebble substrates, are positively buoyant, and hatch in 9-32 days depending on ambient temperatures. Larvae hatch at 2-5 mm standard length (SL) near the water surface, and feed on zooplankton while in the pelagia. Retention in nursery areas via local currents is known to influence interannual recruitment success. Young juveniles are almost exclusively demersal over pebble substrates following settlement (~6-7 cm SL) in June. They have broad temperature and depth tolerances, which fully encompass those experienced throughout our study. Older juveniles (2 years and older) behave much as small adults. Maturity is variable and occurs at 3 years of age and older, depending on location.

The generalized life history of Atlantic cod is very similar to that of haddock. The species is distributed across the northern Atlantic Ocean. In the western Atlantic, the species occurs from Cape Hatteras, North Carolina to Greenland. In the eastern Atlantic it occurs from the Barents Sea south to Spain and Portugal. Spawning mainly occurs from March to August, although spawning activity has been noted throughout the year in various parts of its range. Eggs are released in mid-water column, and are positively buoyant. The use of "up current" spawning locations, inshore areas, and retention zones all appear to be important for this species. Larvae hatch at 3-6 mm SL near the water surface and feed on zooplankton prey as they grow from larvae into pelagic juveniles. Juveniles settle into shallow water in coastal areas or offshore banks in late summer and autumn; cod are demersal thereafter. Preferred substrates include those affording structural cover. Larger juveniles (>20 cm SL) are tolerant of a wide range of depth, temperature, and salinity conditions, which fully encompass those found throughout our study area.

The haddock stock on the eastern Scotian Shelf shows a gradually increasing trend in abundance through time since 1970. This trend has been punctuated by several periods of elevated abundance, e.g., throughout the 1980's and again in the late 1990's to the present (Fig. 1). Our study was conducted following a period of very high recruitment. Through the study years 2002-05, haddock abundance declined in the study area. In the last two decades, haddock size-at-age has steadily declined compared to earlier years. Distribution of haddock on the eastern Scotian Shelf in this decade has been concentrated predominantly on the shallow (<91 m) offshore banks (Fig. 2), consistent with haddock throughout their range. Research vessel data also support our a priori assumption that the study area generally is a recruitment area for young haddock. In contrast to haddock abundances, Atlantic cod abundance was low and sparsely distributed in the study area throughout our study period.

Prior to beginning our study, we conducted a literature review to identify what was known at that time about the habitat associations of demersal fishes on the Scotian Shelf emphasizing juvenile haddock and Atlantic cod (Linehan 2004). We identified over 200 papers on various subjects, including: feeding, distribution, migration and predator interactions, in addition to habitat associations. The selection criteria for inclusion of research studies in the review were: (1) conducted in Atlantic Canada; (2) dealing with juvenile demersal fish; and, (3) dealing with juvenile demersal fish distribution correlated with substrate types and temperature (if used as a habitat variable). Ultimately, 34 studies were selected for detailed review. Most of these studies involved common commercial species and the predominant habitats included both physical and biogenic structures (Table 1). The pervasive theme of the selected studies was that juvenile life stages of demersal marine fish have the strongest fish-habitat interactions. Therefore, emphasis on juvenile stages for the purposes of identifying "critical" fish habitat was typically recommended in all studies. The studies used the terms - "critical", "essential", and "important"-interchangeably to mean similar things. Haddock studies predominantly reported distributions, whereas only two haddock studies investigated haddock-seabed habitat associations. These two studies reported that juvenile haddock inhabit areas with seabeds consisting of large pebble/gravel deposits and coarse sand/gravel. Predominant emergent issues among the studies reviewed were:

- Spatial scale
- Fishing impacts
- Conservation strategies (e.g. MPAs/closed areas, and fishing gear restrictions)

Table 1. Predominant habitat reported in the scientific literature for juvenile demersal fish (Linehan 2004).

	Mud/ Silt	Sand	Sand/ Gravel	Pebble/ Cobble	Boulder	Burrows/ Biogenic Depressions	Shells	Tubes	Sea Scallops
Atlantic cod			X	X	X				
Haddock			X	X					
American plaice		X							
Yellowtail flounder		X							
Witch flounder						X			
Flounder						X			
Ammodytes spp.		X							
Fourspot flounder		X							
Silver hake		X				X		X	
Gulf Stream flounder	X								
Tilefish						X			
Ocean Pout						X	X		
Little skate							X		
Red hake						X	X		X
Spotted hake									X
Snailfish									X
Long finned hake					X	X			
Scup						X			
White hake						X			
Blackbellied rosefish						X			
Longhorn Sculpin						X	X		

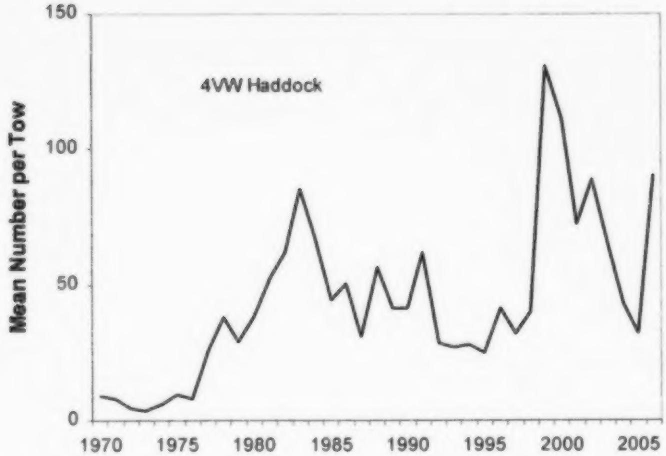

Figure 1. Haddock abundance estimated each year based on Canadian research vessel summer survey on the Scotian Shelf, NAFO Divisions 4VW, 1970-2006.

Figure 2. Distribution of haddock (all sizes) on the Scotian Shelf based on summer Canadian research vessel catches 2000-06.

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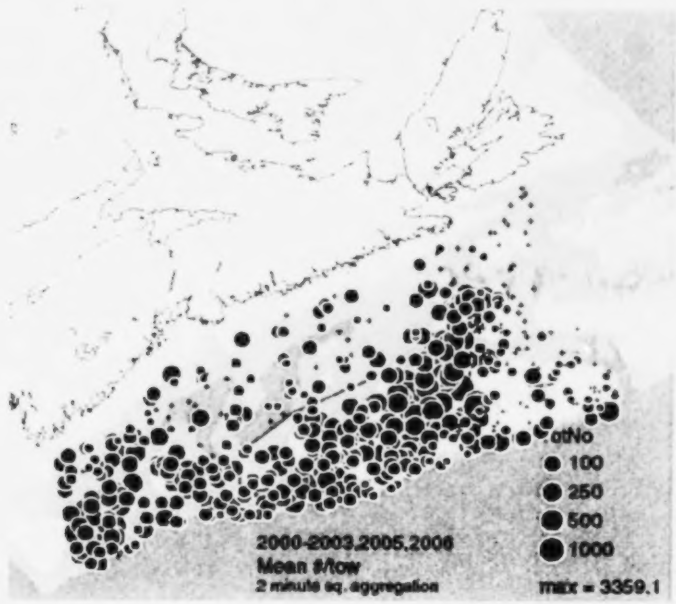

Figure 2. Distribution of haddock (all sizes) on the Scotian Shelf based on summer Canadian research vessel catches 2000-06.

REGIONAL GEOLOGICAL SETTING OF THE OUTER SCOTIAN SHELF

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The Scotian Shelf is divided into three major morphologic regions: inner, middle and outer continental shelf. The outer and middle shelf areas are considered to be part of the Submerged Atlantic Coastal Plain physiographic province and are underlain in the subsurface by Jurassic to Tertiary lithified sediments (bedrock). The outer shelf consists of an archipelago of large isolated shallow banks with intervening channels, depressions and canyons. The depressions connect broad middle shelf basins to the upper continental slope. The outer shelf features are classified as upland areas (banks) and lowland areas (channels and linear depressions). This morphology is interpreted to be the product of preglacial fluvial processes followed by the advance and retreat of glaciers during the Pleistocene. The last major ice advance across the region took place during the Wisconsinan. Glaciers extended across the entire shelf to the upper continental slope at approximately 21,000 years before present (BP). Ice streams are considered to have played a major role in defining the final shape of the banks and their intervening deeper channel and saddle areas. Till (Scotian Shelf Drift) and glaciomarine (Emerald Silt) sediments were deposited during ice advance and retreat across the banks.

Subsequent to the retreat of ice from the outer and middle shelf, a low sea level stand of approximately -110 m occurred. The sea level continued to rise over the following 15,000 years. The outer banks were sub-aerially exposed prior to the marine transgression and the previously deposited glacial sediments were eroded and modified during the sea level rise. The glacial sediments were winnowed and the silt and clay sized fractions were removed, leaving behind clean sand and rounded gravel deposits as the beach front of the transgressing sea flooded across the banks. This process developed the Sable Island Sand and Gravel Formation on the offshore banks as a residual product of glacial sediment erosion. The Sable Island Sand and Gravel sediments can range in thickness from a veneer lag gravel deposit to 30 m thick sand deposits. The winnowed fine-grained muddy sediments were deposited in the middle shelf basins as the LaHave Clay Formation and over the continental shelf edge in deep water.

Early sediment mapping of the bank areas depicted a regionally flat surface of gravel and sand and considered that much of the surface was relict. Recent multibeam bathymetric mapping and sidescan sonar surveys have shown that the bank seabed retains some relict elements of glacial processes (moraines) and fluvial erosion (small channels), but that the seabed is much more complex with a high degree of sediment patchiness and small scale roughness. A full spectrum of sediment bedforms occurs

ranging through ripples, megaripples, ripples in gravel, sand ribbons to large sand ridges. Most of the bedforms appear active with well-defined crests and other characteristics suggesting recent formation and modification. Regional net sediment transport across the outer banks of the Scotian Shelf is from southwest to northeast, largely in response to high energy wave and current conditions developed during storms.

DATA MANAGEMENT FOR FISH HABITAT STUDIES

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The Fisheries and Oceans Canada (DFO) funded a bi-regional research effort to study the question of habitat specificity in juvenile haddock. The Spatial Utilization of Benthic Habitats by Demersal Fish on the Scotian Shelf was designed to determine if acoustic surrogates could be used to estimate juvenile haddock distribution with respect to certain bottom types. The surrogate measurements included sidescan sonar, Biosonics DT and multibeam bathymetry to define bottom classes, and BioSonics acoustic target counts as an estimate of fish densities. Verification of bottom classification was done by use of images (video and stills) and grab samples. Fish densities were verified by standard fish survey trawls and videography.

At the inception of this project, leaders recognized that meeting their ambitious goals was going to be a major challenge given the volume and variety of data they intended to collect and analyze. This recognition led to a decision to include data management in the planning stage.

Using a data management pyramid as a guide, the author presented the steps taken to provide a structured environment and the tools used to collect, process, and archive the data collected to meet the service delivery goal. The data management challenge was to develop a robust set of rules and a systematic way of processing and managing the breadth of data being collected and meet the requirements of the research community in providing products at the highest level of precision and in a timely manner.

The presentation described the software environment that was provided within DFO using the Windows XP environment and noted that this was the first time the group used Geographic Information System (GIS) tools in planning and product development. DFO had invested in ESRI Arcview™ which was used extensively in planning both at semi-annual meetings and at sea. A key decision was to integrate data by ensuring that all data streams were 'tagged' with the Greenwich Mean Time (GMT) time, which is broadcast as one of the navigation stream values aboard each of the research vessels. The concatenation of the ordinal day and GMT time was referred to as GPS time through the presentation. To keep track of the data collected and processing stage reached, a spreadsheet Status Report was described and a nomenclature developed to identify processed datasets within the file structure, and as layers within the GIS document. A project requirement included a means to share data collected and processed between participants. A Microsoft XP secure, shared file structure was also

described as a home for these data. The directories were organized into a logical tree that was reflected in the GIS document. An added feature included upload directories as a control point to receive new data. All data loaded into the file system was done by the data management group to ensure content quality and record keeping.

At sea collection was described as an intense concentrated effort where data management served several functions including station keeping annotation, hardware and software integration and policing of metadata collection. An in-house software program called CAROL was used to manage station keeping metadata. CAROL is a simple form driven user interface program that takes advantage of serial communications input of GPSTime to allow simple flagging of operation events for specific types of collections. In addition to the station keeping annotation, CAROL also has a benthic classification and biological event (Class/Event) sub-window that allows the referencing to features seen during image collection. The output is an ASCII (American Standard Code for Information Interchange) text file with proprietary NMEA (National Marine Electronics Association) strings for ease of processing. Imaging was extensively used as a source of data in this project. CAROL annotation allowed for clear referencing of events in space and time and allowed analysts to identify where events would have been mapped within the collected images. The video images included data overlays and an audio encoding system was used to write essential metadata to one of the audio tracks to allow decoding on playback.

The processing of metadata was an important component of the data management function. It was noted that ship's positions using GPS systems identify antenna but not instrument locations. Navigation data has to be processed for drop point or towed position relative to the antenna. These corrections were time consuming due to malfunctioning instrumentation and an effort was made to document all corrections. A MSAccess database (SUBHADFISH), with CAROL data processing modules, and some of the details in the translation of sidescan sonar mosaics to GIS polygons was also described.

Proper attention to the data management function has contributed to many facets of the project. A description of some of the products and examples of the 'value added' of this effort was discussed.

The presentation concluded with a description of how the data management work for this project is contributing to several other projects and national initiatives. The use of a geo-spatial data model is being investigated and an image archive solution being implemented. Also noted was the development of a video post-processing software package that utilizes the previously described audio encoding feature as part of the ongoing support for this kind of work. Finally, the presenter noted that that he felt confident that the decision by the proponents to invest in data management has, and will, continue to prove its value as this tremendous dataset is studied over the next several years.

FISH COMMUNITIES WITHIN THE SCOTIAN SHELF HABITAT STUDY AREA: OBSERVATIONS FROM TRAWLING

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Historical research vessel trawl data were analyzed to determine spatial distributions of juvenile haddock (*Melanogrammus aeglefinus*) and identify preferred and non-preferred areas on the eastern Scotian Shelf (Anderson et al. 2005). Fish trawling has a long history and considerable research has been done to understand species specific bottom trawl catchabilities (e.g. Fernö and Olsen 1994). The research trawl is both our link to the past and the standard by which we can determine current fish abundance and distribution. The purpose of this study was three fold: first, determine if juvenile haddock and Atlantic cod abundances in 2002 and 2005 were different between the historically identified preferred and non-preferred areas; second, collect biological samples to verify the acoustic (Anderson et al. 2007a) and video (Anderson et al. 2007b) fish remote sensing data and, finally, to collect stomach samples to determine diet and links of haddock and Atlantic cod (*Gadus morhua*) with their environment (Kenchington 2007); and third, to determine the multi-species fish communities within and among the study areas.

Sampling was carried in 2002 during day and night periods and 2005 trawling was carried out during day, dawn, night and dusk periods using a three-bridle Campelen 1800 mesh shrimp trawl (Engas and Godo 1989) outfitted with rockhopper groundgear consisting of tightly packed 14 inch rubber discs and spacers (Walsh and McCallum 1997). Rockhopper groundgear is widely used to reduce net damage on rougher bottoms and it is more efficient than bobbins gear in catching fish close to the bottom. The efficiency of the Norwegian sampling trawl and representative sampling of all size classes have been improved with rockhopper groundgear. (Engas et al. 1988). Mesh size in the trawl varied from 80 mm in the wings to 60 mm in the square and first bellies and 44 mm in the remaining bellies and codend. A 12.7 mm mesh liner is used in the extension piece and codend. The small meshes in the trawl minimize the problem of escapement of young gadoids. Trawl spread was attained with 3.1 x 1.8 m 1400 kg Morgere cambered oval doors. Hydrodynamically efficient doors generate much narrower and lower sand clouds that do not propagate inwards and do not compromise overall catching efficiency compared to less efficient designs.

Trawl depth, headline height, wing spread, door spread, and bottom contact were monitored using SCANMAR™ sensors. On average the vertical trawl height was 4.5 m, wing spread was 15-16 m and door spread was 35-40 m. Effort was standardized by fishing for 15 minutes along bottom once the trawl had settled, as observed from the SCANMAR readings. In 2002, four sets were carried out in each of the detailed areas

(see Gordon 2007) stratified along the 5 km sampling corridor and 48 sets were done over a systematic sampling grid encompassing all areas (total = 72 sets, Fig. 1). In 2005, sampling was stratified along pre-determined 10 km lines within the 10 x 10 km areas (total = 72 sets). All fish species were sorted from each catch and total biomass was determined. A representative length sample was obtained for all species. In addition, detailed sampling was carried out on cod and haddock including biomass and sex determination. Stomachs were placed in saline solution and frozen for subsequent analysis (Kenchington 2007).

A total of 35 species were caught in 2002 and 40 species in 2005 throughout the six study areas. Species diversity (Shannon Weiner Index) did not differ among the study sites in either year but species richness was highest in the Sable Island Bank preferred area in both years. In 2002, the most frequently occurring and most abundant species was haddock (Table 1). In 2005, yellowtail flounder (*Limanda ferruginea*), silver hake (*Merlucius bilinearis*), longhorn sculpin (*Myoxocephalus octodecemspinosus*), and Atlantic cod (*Gadus morhua*) occurred in all 72 sets (Table 2). Sandlance (*Ammodytes* spp.) was notable for its high abundance in spite of its known low catchability in the bottom trawl. The highest mean abundance of all species combined occurred in the preferred areas on Sable Island Bank and Western Bank in 2002 and in the preferred area on Emerald Bank and the non-preferred area on Western Bank in 2005.

Haddock were dominated by the abundant 1999 year-class as three year olds approximately 30 cm in length in 2002. In 2005, the 1999 year-class was still abundant in all areas being around 40 cm in length. Haddock were caught in all six study areas occurring in 93% and 90% of all sets in 2002 and 2005, respectively (Table 1). In 2002, juvenile haddock (<26 cm) were 10 and 38 times more abundant in the preferred areas on Western Bank and Sable Island Bank, respectively, but were equal in abundance in the two areas on Emerald Bank in comparison to the non-preferred areas. We regard one or more order of magnitude differences in abundance as significantly different. In 2005, juvenile haddock were 15 and 46 times more abundant in the preferred areas on Western Bank and Sable Island Bank, respectively, and again were approximately equal in abundance on Emerald Bank. We conclude from these results that juvenile haddock were significantly more abundant in the preferred areas on Western Bank and Sable Island Bank, consistent with the historical research vessel data. However, we did not measure differences in abundance between the areas on Emerald Bank. Therefore, it appears that juvenile haddock selected the preferred areas on Western Bank and Sable Island Bank and that these areas must represent better habitat. The lack of difference between areas on Emerald Bank suggests habitats were not different. In contrast, juvenile Atlantic cod (<26 cm) abundances were not different between the preferred and non-preferred areas on all three banks. Ratios ranged from 1.4 to 2.3 times more abundant in the preferred areas to 1.2-7.1 times more abundant in the non-preferred areas both years. We do not regard these abundances to be significantly different. The only exception for Atlantic cod was the higher abundance in the preferred area on Emerald Bank in 2005 (13:1). Therefore, we conclude that juvenile Atlantic cod did not select the preferred areas over the non-preferred areas.

In 2005, abundance of juvenile haddock decreased in all areas on Western Bank and Sable Island Bank being three to four times lower compared to 2002. On Emerald Bank abundance increased in both the preferred and non-preferred areas by a factor of approximately four times higher than 2002. The increase in abundance on Emerald Bank was both one and two year old haddock. In contrast, juvenile Atlantic cod were more abundant in all areas on all three banks compared to 2002. The increase in abundance was highest on Emerald Bank where abundances increased by 22 times in the non-preferred area and 121 times in the preferred area. On Western Bank and Sable Island Bank abundances in 2005 increased by a factor of two to six times compared to 2002. Therefore, there was significant recruitment of juvenile Atlantic cod on Emerald Bank and notable increases in abundance on Western Bank and Sable Island Bank in 2005 compared to 2002. However in 2005, haddock were still three times more abundant than cod in the preferred areas on Western Bank and Sable Island Bank. The largest increases in abundance of Atlantic cod occurred in the non-preferred areas on Western Bank and Sable Island Bank. These results support the conclusions that juvenile haddock actively select the preferred areas and continue to exclude Atlantic cod from these areas even though the abundance of cod was higher in 2005.

Table 1. Abundance and biomass of the twenty most abundant fish caught in the trawl surveys in 2002. Biomass (kg) was based on measured weights. Occurrence (%) – refers to the frequency of occurrence of each species in the trawl sets.

Rank	Species	Occurrence (%)	Number Caught	Biomass (kg)
1	Sandlance	71	119,068	1,991
2	Haddock	90	15,667	6,330
3	Yellowtail flounder	100	11,290	974
4	Silver hake	100	8,276	1,313
5	Longhorn sculpin	100	6,217	682
6	Atlantic cod	100	5,713	1,464
7	American plaice	85	2,301	107
8	Winter flounder	75	2,086	244
9	Herring	28	1,708	335
10	Atlantic mackerel	17	207	39
11	Sea raven	53	182	83
12	Red hake	58	175	27
13	Mailed sculpin	17	130	1
14	Little skate	26	86	48
15	Winter skate	22	60	56
16	White hake	18	57	7
17	Monkfish	18	24	43
18	Vahl's eelpout	15	24	3
19	Witch flounder	13	19	5
20	Alligatorfish	10	13	0.1

Table 2. Abundance and biomass of the twenty most abundant fish caught in the trawl surveys in 2005. Biomass (kg) was based on measured weights. Occurrence (%) – refers to the frequency of occurrence of each species in the trawl sets.

Rank	Species	Occurrence (%)	Number Caught	Biomass (kg)
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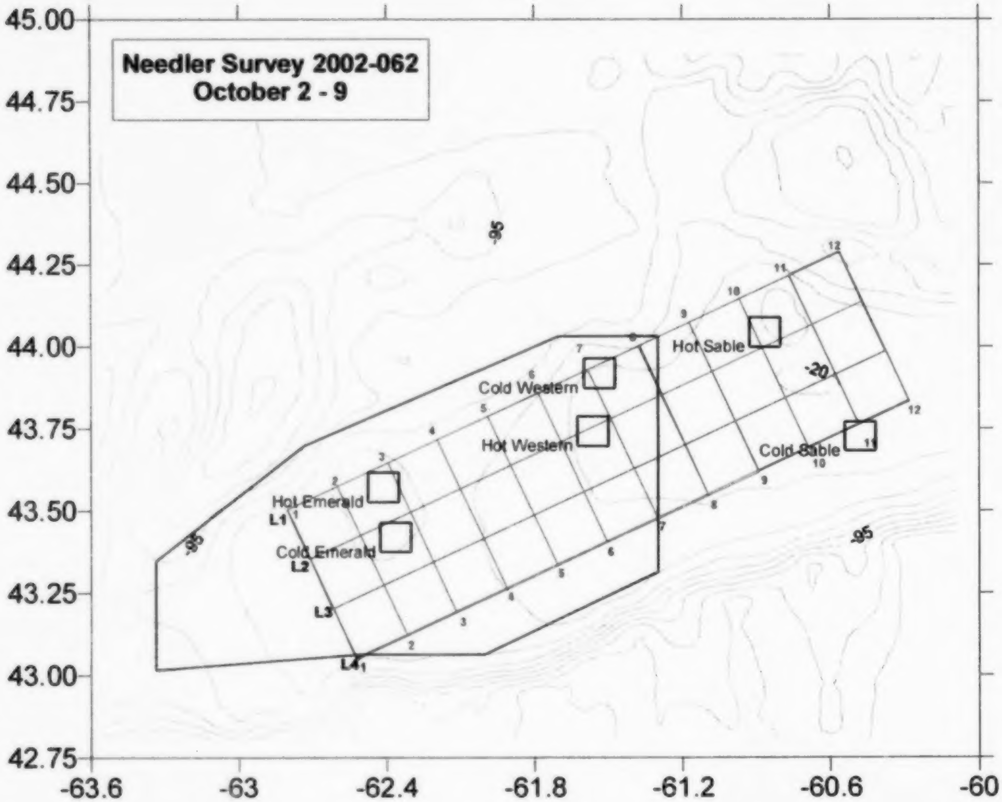

Figure 1. Study areas on the eastern Scotian Shelf (blue squares) and the 48 station systematic sampling grid (red rectangle). Depth contours are labeled at 20 m and 95 m. The Haddock Closed Area lies within the green polygon.

SEABED HABITATS AS REVEALED BY MULTIBEAM SURVEYS

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Three study areas from the spatial utilization of benthic habitats by demersal fish project (see Gordon 2007) were surveyed using high-resolution multibeam echosounder technology. The preferred sites on Western Bank and Sable Island Bank have historically supported higher abundances of juvenile haddock (Anderson et al. 2005). The third, non-preferred, site on Western Bank has been characterized by lower fish abundance (op. cit.). Multibeam mapping technology is now routinely used to provide the underlying mapping context for benthic habitat studies around the world. The purpose of the multibeam surveys was to characterize and contrast the physical seabed habitats in these areas, to assess the efficacy of this approach to habitat assessment in comparison to other more traditional methods, and to assess the application of classification methods to derive seabed type from acoustics parameters.

The continental shelf of mainland Nova Scotia extends some 200 km offshore. It comprises a series of shallow (<200 m) outer banks, with surficial deposits of sand and gravel, separated from the nearshore coastal ramp by mid-shelf basin systems that are characterized by finer grained sediments (silts and clays). The surficial geology of the Scotian Shelf, at least in the broad sense, was mapped by the Geological Survey of Canada in the 1970's. The geological maps, however, do not distinguish the geological character of the project study areas where Western Bank is classified as Sable Island sand and gravel with <50% sand and Sable Island Bank is classified as Sable Island sand and gravel with <50% gravel.

In 2005, the Canadian Forces Auxiliary Vessel (CFAV) *Quest* was chartered by the Fisheries and Oceans Canada to the conduct multibeam surveys. A Reson 8125 multibeam echo sounder was deployed from a pole mounted off the starboard aft quarter of CFAV *Quest* to collect bathymetric and backscatter data. This sounder operates at a frequency of 455 kHz with a nominal depth resolution of 6 mm. It projects 240 beams over an arc of 120 degrees under the vessel. The system has a very narrow beam width of 0.5 degree yielding a footprint of less than 0.5 m in 50 m of water. Motion reference unit (MRU), heading, and differential GPS (DGPS) data were collected simultaneously and were logged with the QUINSy multibeam logging package. Sound speed profiles were collected every 9-12 hours depending on local oceanographic conditions. QUINSy database files were exported in XTF format and the data were imported into Caris HIPS for visual inspection, sound speed profile integration and cleaning. Caris HDCS files were exported to GRASS and bathymetric grids were generated at 0.5 m, 1 m, 2 m, 4 m and 8 m grid cell resolutions using beam-dependent error models and anti-aliasing filters. Colour-shaded relief maps and numeric grids were

generated for inclusion in the database project (see Clement 2007). Backscatter data from the Reson system are not well managed through Caris HIPS. Software was developed in-house to export the range-intensity-travel time data in the XTF files to a generic sensor format (GSF). These GSF files were then imported in GRASS for subsequent processing and production of backscatter mosaics.

Colour shaded bathymetric relief and backscatter images of the three study areas show a wealth of detail and structure in all of the three study areas (e.g. Fig. 1). In these images, the colour shaded relief map spans a depth range of 10-15 m with red tones being the most shallow. In the gray scale backscatter map, light to white tones generally map low-backscatter sand substrates while the darker tones map progressively coarser grained gravels. Detailed examination of the highest resolution bathymetry mosaics reveals the presence of individual boulders and gravel ripples with horizontal wavelengths of a few meters and amplitudes of 20 cm within different sections of the three study areas.

The large-scale bedforms on Western Bank trended in the south-east to north-west direction which are transverse to the prevalent direction of south-west/north-east storm systems which dominate sediment transport in this area. In contrast, the bedforms in the Sable Island Bank area were oriented parallel to the main direction of sediment transport. Previous studies have recognized the shore-face attached ridge bedforms near Sable Island characterize the area. Although all three study areas were relatively complex in structure and nature, the preferred areas generally showed more complex inter-fingering between the high and low backscatter terrains while the low backscatter spatial distributions in the Western Bank non-preferred area were much more massive and spatially contiguous.

The backscatter response of the seabed is a complex function of seabed roughness, seabed hardness, and sub-surface volume heterogeneity. The amount of signal power scattered back from the seabed is consequently a strong function of the angle of the impinging acoustic beam. In preparing backscatter maps this angular response function has been averaged out and backscatter estimates were normalized to an angle of incidence on the seabed of 45 degrees. Backscatter estimates near this angle emphasize the micro-scale roughness of the seabed, a scale proportionate to the wavelength of the sounder, approximately 3 mm for the Reson 8125. Although this approach results in backscatter maps that show less pronounced survey line artifacts, producing "better-looking" images, the information relevant to other scattering processes at nadir (0 degrees) and wide-angle (>45 degrees) have been minimized if not removed.

At angles approaching normal incidence, the reflection of the beam off the seabed is dominated by a direct reflection of the impinging acoustic pulse. The strength of this reflection depends on coherent phase reflections from within the area of the Fresnel zone of the beam on the seabed. For wider angles off-axis, the return is dominated by small-scale true backscattering of the surface and sub-surface of the seabed. These two scattering processes are influenced by seabed roughness at

different horizontal scales. Nadir zone scattering estimates are more highly affected by the meso-scale roughness of the seabed, a scale comparable to the footprint of the sounder (around 0.5 m).

Techniques were developed in this project to measure the nadir response; i.e. a metric describing the amplitude of the backscatter response for acoustic beams pointed directly at the seabed. The nadir anomaly response is calculated as the deviation of the nadir response from the normalized backscatter value; that is, the difference between the observed backscatter at nadir and the normalized backscatter estimate at nadir calculated using the 45 degree off-axis averaging function. Since the distribution of nadir points is finely sampled along the ship track, directly under the sonar but the tracks are separated by the survey line spacing at ~100 m, the map of the nadir response must be filtered to reduce aliasing effects resulting in a smoother estimator for this metric. Thus, the map of the nadir response is only available at longer wavelengths (>0.5*line spacing) and some of the detail evident in the normalized backscatter maps have been averaged out.

High values of the nadir response indicate a meso-scale smooth seabed while low-values of the nadir response indicate a meso-scale rough seabed. It is postulated the normalized backscatter map and the nadir anomaly map approach the 1st and 2nd principle components of a principle component analysis (PCA). Previous work has suggested that up to 80% of the discriminatory information is contained in the 1st principle component.

An example of the nadir anomaly response for the Western Bank preferred area is shown in Fig. 2, with the corresponding nadir response map shown on the right. Generally, the highest (red) values of the nadir response correspond to the lowest amplitude (sand) returns on the normalized backscatter map while the lowest values of the nadir response (blue) correspond to the higher (gravel) values of backscatter. This can be understood in the following way. A locally smooth (on the scale of the beam footprint) seabed is most likely a finer grained, sandy substrate since tide- and wave-induced transport has been shown to continually re-suspend these materials on a daily basis, smoothing out the large scale topography. Coarser gravels, in contrast, are only transported in peak storm events and the morphology of the gravel bedforms often reflects a configuration developed under high-energy conditions.

The assumption that roughness measurements at one scale can predict roughness estimates at a different scale often does not hold. The correspondence between the normalized backscattered maps and the nadir anomaly amplitude is, therefore, not always one-to-one and this added layer adds extra information to constrain the classification of the seabed into distinct bottom types. The difference is particularly important when there exists different bedforms within areas with similar grain sizes (similar wide angle backscatter response). It has been observed in these circumstances that the normalized backscatter response, alone, is ambiguous and it is hoped that the inclusion of nadir data will help reduce this ambiguity.

An unsupervised cluster analysis, (GRASS routine i.cluster) was performed on the normalized backscatter and the nadir anomaly map layers for the three study areas. The cluster analysis suggested that the map layers could support at least four distinct classes. The cluster parameters were remarkably similar for the three study areas although the cluster analysis on each site was performed independently. The cluster results were then used to segment the maps into each of the four cluster classes using a maximum-likelihood approach (GRASS routine i.maxlik). These classified maps agreed exceptionally well with interpretations of the geology of the area based on traditional methods (see Fader 2007).

(a) (b)

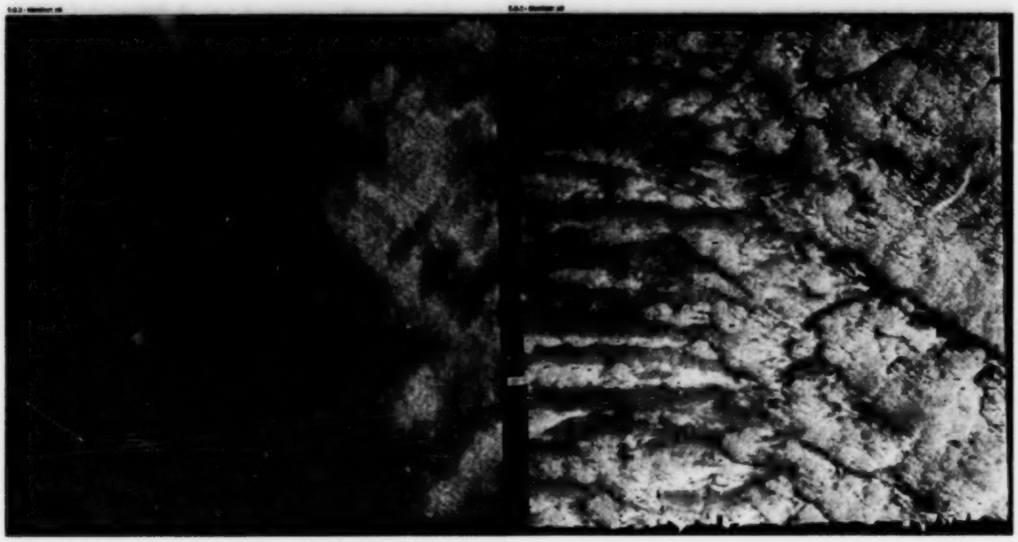

Figure 1. Multibeam bathymetry map (a) and normalized backscatter map (b) for the Western Bank preferred area.

(a) (b)

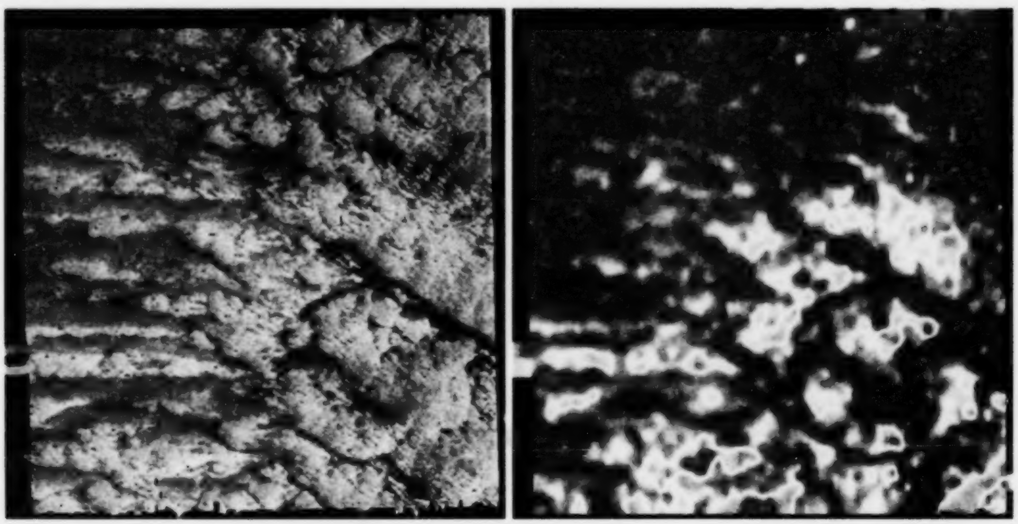

Figure 2. Normalized backscatter map (a) and nadir anomaly map (b) calculated for the Western Bank preferred area.

SEABED SEDIMENT DISTRIBUTIONS, MORPHOLOGY, DYNAMICS AND FEATURES OF DETAILED STUDY AREAS ON EMERALD, WESTERN AND SABLE ISLAND BANKS, OUTER SCOTIAN SHELF

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Detailed study areas (preferred and non-preferred) were selected on Emerald, Western and Sable Island Banks to best represent the varied morphology and sediment distributions of outer Scotian Shelf banks based on 100 km^2 reconnaissance surveys at six locations. Detailed seabed surveys were conducted in 5 km^2 areas on each of the banks using high resolution sidescan sonar systems and echosounders that were followed by video transects, bottom photography and seabed sampling to provide ground truth for sediment interpretation. Sidescan sonar mosaics were constructed at 0.25 m resolution. The interpretation of seabed sediment texture from the sidescan sonograms was based on relative backscatter and sediment boundaries were both sharp and gradational. Bedforms occurred on sand and gravel sediments (Wentworth scale) and their amplitude, wavelength, symmetry, and relationships were mapped. Other features such as moraines, gravel ridges, boulders, boulder fields, superimposed sand bedforms, and zones of sand ribbons occurred across the seabed and were also mapped. The seabed morphology and dynamic sediment features of the study areas are much more complex than indicated by previous surveys.

Four sand and ten gravel units were identified and defined on the basis of sediment grain size, morphology and superimposed dynamic bedforms (Table 1). Additionally, zones of boulders and sand ribbons, individual boulders, and the orientations of bedform crests were mapped. The sandy sediments are actively moving in most areas and the gravel ripples composed of granules, pebbles and cobbles are interpreted to reform during large storm events. Smaller regions of the study areas such as glacial moraines are relict and retain characteristics formed during the original deposition of the material. Flat lag gravel surfaces and fields of rounded boulder are also relict and associated with a marine transgression in early post glacial time. Patchiness, as a measure of the relative size, shape and density of the distribution of surficial units, was highly variable among study areas.

Serial surveys show that only minor variations in the distribution of the surficial sediments occurred. Bedforms appear to alter their wavelength and orientation and boundaries of units shift slightly. However, the regional patterns of sediment distribution, bedforms and patchiness remain the same.

A comparison of the multibeam bathymetry and associated backscatter with the sidescan sonograms shows a high degree of correlation between sand and gravel

distributions. However, at 2 m resolution the multibeam systems cannot portray the smaller bedforms on gravel and sand. Multibeam imagery at 0.5 m resolution, the highest resolution attainable with the systems that were used, can detect some of the larger gravel bedforms and many more boulders. Backscatter from the multibeam imagery appears uniform over varying wave length gravel ripples. Comparisons between the sidescan and multibeam imagery indicate that the sidescan imagery has the highest resolution and can detect very subtle variations such as multiple overlapping bedforms that cannot be detected with the multibeam bathymetry or towed video. Multibeam bathymetry clearly shows subtle morphological variations not seen on the sidescan imagery.

A comparison of the preferred and non-preferred study areas shows that the preferred areas are patchier with a larger number of sand and gravel polygons. The non-preferred areas consist of a smaller number of larger polygons. Rippled gravel areas are more widespread on the preferred sites and the non-preferred sites show more regions of continuous sand with areas of superimposed sand megaripples.

Table 1. Summary of geological classes interpreted from the sidescan mosaics with reference to sediment particle size analysis and photographic records.

Interpreted Sediment Units (ISU)

1G	GRAVEL
1GS	Gravel to gravely sand
1GR	Gravel ripples
1GRS	Gravel ripples, short wave length
1GRL	Gravel ripples, long wave length
1GRI	Gravel ripples, incised
1GL	Gravel lag
1GH	Gravel, hummocky
1GSP	Gravel with small sand patches
1GSRT	Gravel with sand ribbon troughs
2S	SAND
2SM	Sand with megaripples
2SG	Sand to sandy gravel
2SB	Sand with scattered boulders

Mapped Features and Zones

Boulders
Sand ribbons
Gravel ripple crests
Gravel ridges
Zone of boulders
Zone of sand ribbons
Zone of starved megaripples

ACOUSTIC SURROGATES FOR DEMERSAL FISH HABITATS ON THE SCOTIAN SHELF: JUVENILE HADDOCK AND ATLANTIC COD

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A multi-disciplinary program of research on the eastern Scotian Shelf (Canada) identified preferred and non-preferred 100 km^2 areas for juvenile haddock based on historical distributions (Anderson et al. 2005). An extensive research program is now underway to characterize and contrast abiotic and biotic variables within and among these areas towards defining fish habitat for small (<26 cm) juvenile haddock (*Melanogrammus aeglefinus*) and Atlantic cod (*Gadus morhua*). The primary purpose of this study was to develop simple acoustic measures to characterize the seabed using normal (i.e. vertical) and oblique incidence acoustic systems. When acoustic measures differ among preferred and non-preferred areas then these may serve as surrogate measures of fish habitats. A secondary purpose was to compare the normal and oblique incidence systems which are expected to measure different properties of the seabed backscatter response (Courtney et al. 2005).

A BioSonics DT-X 120 kHz dual beam echosounder was used to collect normal incidence data along 10 km lines for each of the six 100 km^2 study areas and within these areas along 5 km lines within smaller 5 km^2 areas (see Gordon 2007). The average observational (i.e. measurement) distances along transects were 17 m and 8.5 m, respectively. These data were used to generate bathymetric surfaces at 400 m and 50 m grain size, respectively, in order to generate 1 m depth contours for each of the sampled areas. In addition, the differences in depth between adjacent observations was used to calculate bathymetric relief (m m^{-1} $\cdot 10^{-3}$). The acoustic backscatter data were used to determine water depth (m) and seabed backscatter intensity (dB) within 5° of nadir (R1) and between 10° and 25° off nadir (R2) (Anderson et al. 2005; Courtney et al. 2005). Generally, R1 measures facet scattering and acoustic impedance (hardness) while R2 is expected to measure acoustic impedance contrast, microscale roughness and sub-surface volume scattering. As a true measure of R2 we used a Simrad-Mesotech MS992 120 kHz sidescan sonar within the 5 km^2 preferred and non-preferred detailed study sites on Western Bank. We spatially matched the corresponding acoustic backscatter from the sidescan sonar, where the average footprint of the normal incidence system was 80 m^2. Mean and variance of the sidescan sonar backscatter

intensity (dB) normalized to 60° off nadir were estimated to compare with the normal incidence system.

Comparison of the bathymetric surfaces demonstrated that depth ranges were greater within the preferred study areas for all three banks, differing by 2 m on Emerald Bank, 5 m on Western Bank and 4 m on Sable Island Bank for the 100 km^2 areas. Similarly, the depth range for the 5 km^2 detailed study areas was 3 m on Western Bank and 4 m on Sable Island Bank. This relationship broke down only within the detailed study areas on Emerald Bank where the non-preferred area had a 2 m greater range in depth. Overall, this simple metric demonstrates a greater range of bathymetric depth for the preferred areas within each bank at a scale of 10 km and this relationship was still apparent at the smaller spatial scale of 5 km, except on Emerald Bank.

Bathymetric relief ($m\ m^{-1} \cdot 10^{-3}$) was always greater in the preferred areas on all three banks and ranked highest for the preferred area on Sable Island Bank followed by Western Bank and Emerald Bank. The non-preferred areas had lower bathymetric relief on Western Bank followed by Sable Island Bank and finally Emerald Bank. The overall ranking did not change for the 10 km and 5 km data sets with the exception Emerald Bank and Sable Island Bank non-preferred areas changed rank as the lowest areas of bathymetric relief. These results indicate that the preferred areas had higher seabed rugosity (surface area divided by planar area) and that this occurred at a spatial scale of at least 100 km^2. The de-correlation scales of bathymetric relief demonstrated that rugosity spatial scales were smaller in the preferred areas and that the relationships were dependent on the size of each bank (Anderson et al. 2005). Scale analysis demonstrated that surface rugosity occurred at spatial scales of <10 m in all areas. Identifiable spatial scales also occurred from 500 m to 1100 m in the preferred areas on Western and Sable Island Banks and the non-preferred area on Emerald Bank. In the remaining three areas spatial scales were greater than we could resolve with 10 km transect data. Overall, we conclude that seabed habitats were more complex at smaller spatial scales within the preferred areas.

Backscatter data from the normal incidence fisheries acoustic system (R1, R2) and the oblique incidence sidescan sonar system (mean, variance) demonstrated there were four unsupervised acoustic classes on Western Bank. The two dominant acoustic classes were clearly related to sand and gravel habitats at spatial scales of 100s to 1000s of meters. In the preferred area, spatial scales ranged from 250 m to 800 m compared to the non-preferred area where spatial scales were >1000–3000 m. Similar results occurred for either acoustic system alone, demonstrating there was no advantage in combining these two sensor types for the sand and gravel substrates observed in this study (Courtney et al. 2005). There was no consistent spatial coherence between the four acoustic classes and the seven to eight interpretted surficial geological classes within the preferred and non-preferred areas on Western Bank. Our analysis demonstrated that the absolute or even relative, level of sonar backscatter intensity is the primary means of distinguishing substrate.

COMPARISON OF ABUNDANCE AND DISTRIBUTION OF JUVENILE GADOIDS BASED ON TRAWL, ACOUSTIC AND VIDEO OBSERVATIONS

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Estimates of abundance and distribution of haddock (*Melanogrammus aeglefinus*) and Atlantic cod (*Gadus morhua*) were made using three different fish capture systems within the preferred and non-preferred areas on Western Bank and Sable Island Bank during autumn 2002. Trawling was done using a Campelen 1600 modified shrimp trawl (Dalley et al. 2007). Trawl sets were done two to eight days following the acoustic and video estimates. The trawls were spatially stratified within 1 km x 5 km study sites during both day and night. Haddock and Atlantic cod captured by the trawl averaged 29.7 cm and 29.1 cm in length, respectively. Haddock and Atlantic cod (m^{-2}) were detected acoustically using a calibrated BioSonics DT-6000 38 kHz split beam acoustic system (7° beam angle, 0.4 ms pulse width, -54 dB threshold, 1 pps) boom mounted at the surface (Anderson et al. 2007). Fish (m^{-2}) were detected visually near the seabed using Towcam, a purpose built towed video system flown 2.5 m above the seabed and fitted with a Sony XC-999 colour video camera recording to a DVCAM (digital video camera recorder) for post processing (Gordon et al. 2000). A TrackPoint II system was used to position the Towcam over the seabed. Acoustic and video systems were operated simultaneously sampling at approximately 1.25 m s^{-1} along two 5 km transects both day and night. All data were geo-referenced based on dGPS data. The average footprint of the acoustic system was 7 m across by 12 m along transect and for the video system was 3 m across by 5 m along transect. It was not possible to distinguish between haddock and Atlantic cod for the acoustic and video fish data. Therefore, all observations were combined and subsequently partitioned into haddock based on the trawl catch ratios (Dalley et al. 2007) for abundance comparisons within each study site.

Fish abundance was ranked similarly by all three fish capture systems among the four study sites and all three systems ranked the preferred sites higher than the non-preferred sites (Fig. 1). The only exception in overall ranking was the trawl estimate for the Western Bank non-preferred site which ranked lower than Sable Island Bank non-preferred compared to both the acoustic and video abundance estimates. Overall, these results demonstrate that the acoustic and video fish data accurately measured abundance among the areas. There was significant diurnal variation in the abundance estimates of all three systems. The trawl captured more fish during day time (2.1:1) compared to night. By contrast, both the acoustic and video systems detected more fish during night (2.3:1 and 2.6:1, respectively). These results are consistent with haddock and Atlantic cod descending to the seabed during daylight and rising and dispersing into the water column at night (e.g. Korsbrekke and Nakken 1999). We interpret that the

trawl data were aliased low during night time due to fish rising above the trawl headrope whereas during day time fish descended to the seabed and were caught in greater numbers. The acoustic data would be aliased low during day time due to non-detection of haddock and Atlantic cod on the seabed and occurring within the acoustic deadzone. The video data would be aliased low during day time if there was greater avoidance of the towed system through visual detection of the Towcam at greater distances.

Fish distributions within each study site were compared for the acoustic and video data collected along transects. Dispersion indices (Carmago, Simpson) demonstrated that haddock and Atlantic cod were very contagiously distributed (i.e. patchy) during day time and less so during night time for both the acoustic and video data. These results are consistent with fish rising off the seabed at night and becoming more dispersed when predation risk is lower. Comparison of mean fish density with the proportion of zeros measured in each area demonstrated a highly significant negative relationship for both acoustic and video fish both day and night. These results are consistent with a density dependent spatial distribution; when fish density was higher fish spread out over a greater proportion of the seabed. The proportion of zeros along each transect ranged from 27% to 98% for the acoustic fish and from 75% to 98% for the video fish. The higher proportion of zero observations within the video data set is consistent with the lower mean densities compared to the acoustic fish (Fig. 1). This suggests there was a significant degree of avoidance of the Towcam that occurred both day and night. Finally, we calculated the distance between fish observations for both the acoustic and video fish observed along each transect. The highest proportion of observations occurred at the measurement distance of each system, 8 m and 5 m respectively. For acoustic fish more than 50% of the fish were separated by distances <25 m and for the video fish by distances <20 m. For fish observed by the video system 88.7% of a total of 7,990 observations were single fish. Two fish were observed 9.8% of the time and from four to nine fish were observed the remainder of the time. Combined, these observations demonstrate that when juvenile cod and haddock occurred on the seabed they occurred as singletons separated a few meters apart but these distributions were patchy followed where these aggregations of fish were separated by large distances over which no fish occurred. Density distribution analysis demonstrated that fish were distributed at spatial scales of 100s to 1000s of meters (Anderson et al. 2007).

Overall, we conclude that both the acoustic and video fish systems accurately measured the relative abundance of haddock and Atlantic cod among the study sites when compared to standardized trawl catch rates. Both acoustic and video systems under estimated fish abundance during daytime but this did not appear to alias any of the measures of spatial distribution within the study sites along transects. The lower mean density of video fish compared to acoustic fish appeared to result from the high proportion of zero observations along transect but, again, this did not appear to alias the estimates of distribution compared to the acoustic system. The acoustic system appears to more accurately measure the abundance and distribution of haddock and Atlantic cod while the video system provides a measure of species verification as well as direct observations of individual fish at small spatial scales. We conclude that both acoustic

and video systems provided important information on fish abundance and distribution that will be critical to determining small scale habitat associations.

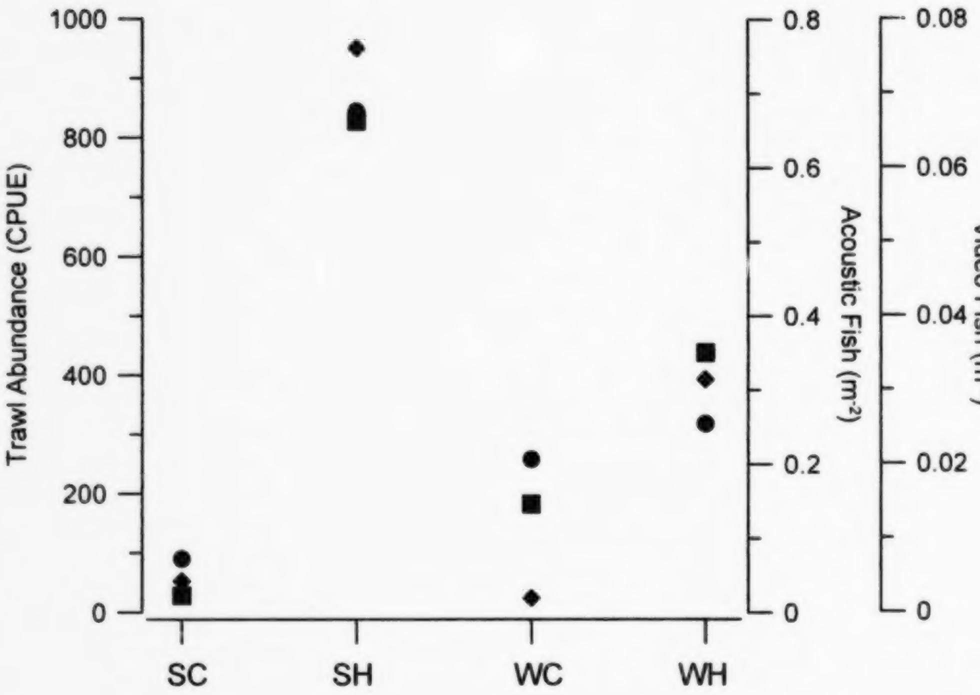

Figure 1. Fish abundance measured by the bottom trawl (catch per unit effort, CPUE), acoustics (fish m^{-2}) and video systems (fish m^{-2}). SC- refers to Sable Island Bank non-preferred area; SH- refers to Sable Island Bank preferred area; WC- refers to Western Bank non-preferred area; WH- refers to Western Bank preferred area.

SCALE DEPENDENT DISTRIBUTIONS OF HADDOCK AND ATLANTIC COD WITHIN PREFERRED AND NON-PREFERRED HABITATS ON THE SCOTIAN SHELF

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Determining spatial distributions of fish is critical to identifying where their habitats occur. Distributions of juvenile haddock (*Melanogrammus aeglefinus*) observed over 32 years were analyzed to identify preferred and non-preferred areas on the eastern Scotian Shelf (Anderson et al. 2005). These areas appeared to be on the order of 100 km^2 or less. An extensive research program is now underway to characterize and contrast abiotic and biotic variables among and within these areas towards defining the shelf habitats of juvenile haddock. A key objective of the research program is to determine the spatial distributions of haddock and Atlantic cod within the 100 km^2 areas, from scales of meters to kilometers. The purpose of this study was to use high resolution fisheries acoustic techniques to measure abundance and distribution of juvenile haddock and Atlantic cod (*Gadus morhua*).

A BioSonics DT-6000 38 kHz split beam echosounder (7° beam angle at 3 dB, 0.4 ms pulse width, -54 dB threshold, 1 pps) was used to collect normal incidence data along 10 km lines for each of the six 100 km^2 study areas and within these areas along 5 km lines within smaller 5 km^2 detailed study areas. Fish targets were detected using the BioSonics Visanal™ detection algorithm. Previously, the only target strength (TS) to length relationship for haddock was based on relatively large fish (40-48 cm, Ona and Hansen 1986). In this study a swim bladder estimation technique was used to estimate the TS-length relationship for the sizes of haddock and Atlantic cod observed in this study. Preliminary information indicates that the TS-length relationship of Ona and Hansen (1896) under estimates fish length. Acoustic backscatter strength (S_A) was estimated by averaging five consecutive pings along each transect and converting S_A into fish density (m^{-2}) using the standard sonar equation (Simmonds and MacLennan 2005). Here we report results from the 5 km^2 study areas sampled in 2002 on Western Bank and Sable Island Bank.

Comparison of lengths estimated from acoustic targets were similar to the lengths of haddock captured by the trawl for the preferred areas on Western Bank and Sable Island Bank (Δ 2.5-2.9%) whereas in the non-preferred areas the fish detected acoustically were significantly smaller (Δ 11.2-13.4%). Overall, haddock captured by the trawl averaged 28.3-31.1 cm among areas compared to Atlantic cod that averaged

28.0-35.6 cm in the preferred areas and 24.4-25.7 cm in the non-preferred areas (Dalley et al. 2007). Therefore, there may have been some influence of smaller Atlantic cod in the non-preferred areas on the TS length estimates. However, the average size of fish estimated by acoustic targets and scaled to length (cm) using Ona and Hansen (1986) in the non-preferred areas was 19.8 cm on Western Bank and 15.0 cm on Sable Island Bank. These lengths were considerably smaller than fish captured by the trawl. These comparisons indicate that the trawl may have under sampled small (i.e. 0-group) fish in the non-preferred areas.

The mean height of acoustic targets detected within 20 m of the seabed was 2.1 m during day light and 3.2 m at night, averaging 0.8 m higher at night time. The mean target strength (dB) at night was slightly lower in all areas. We interpret this as fish being oriented more parallel (orthogonal) with the seabed during day and more tilted at night. Combined, these results indicate that haddock and Atlantic cod rose slightly from the seabed at night and were actively swimming (less orthogonal orientation with the seabed) which is consistent with a more dispersed and active behaviour associated with feeding at night time during lower predation risk.

The distribution of haddock and Atlantic cod (number m^{-2}) detected along transects was analyzed for fish detected within 0.2-3 m above the seabed. The proportion of zeros averaged 75% and ranged from 28% to 98% while the fish density was log-normally distributed. Examination of the fish distributions along transects indicated areas of higher and lower abundance. Cumulative frequency distributions of fish density along each transect were analyzed using least squares regression analysis to detect areas of common slope that were statistically different from adjacent areas ($P < 0.05$). The explained variation for linear distances of common fish density was typically R^2 = 89%. Overall, distances averaged 622-1,207 m within the four study areas. There were no apparent diurnal differences nor were there differences between the preferred and non-preferred areas. The frequency distribution of common distances were right skewed on Sable Island Bank and uniformly distributed on Western Bank. The regression slopes ranged from 0.001 to 0.209 on Western Bank and from 0.000 to 1.059 on Sable Island Bank. While the mean densities of fish were higher in the preferred areas equally high rates of increase occurred within the preferred and non-preferred areas. Preliminary analysis of fish detected from the video in the preferred area on Sable Island Bank indicated areas of common densities were slightly greater than fish detected acoustically, where mean distances of common slope averaged 1270 m compared to 915 m, respectively.

In summary, acoustic targets accurately represented fish lengths sampled by the trawl in the two preferred areas but estimated smaller fish within the non-preferred areas. This may reflect a sampling bias by the bottom trawl that was specific to different seabed habitats. Alternatively, the difference could result from errors in the TS-length relationship for small haddock, where haddock measured by Ona and Hansen (1986) were bigger than observed in this study. Further work based on fish target strength will examine these questions. Fish appear to rise, on average, about one meter from the seabed at night and are more active, presumably associated with feeding behaviour

during darkness when predation risk is lower. Fish distributions along transects were typically from 100s to 1000s of meters. These distributions were not different day or night and were not different among preferred and non-preferred areas. The relatively high rates of increase in density that occurred within the non-preferred areas suggests that suitable habitats occurred at small spatial scales within these areas. Preliminary analysis relating these small scale spatial distributions of haddock and Atlantic cod to seabed substrate demonstrates preference for gravel substrates over sand and for bedform features, such as ripples, over flat landscapes (Ollerhead and Anderson 2007).

JUVENILE HADDOCK AND COD: DIETARY LINKS TO THE BENTHOS

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Fish stomachs from juvenile haddock and cod collected by bottom trawl in 2005 (Dalley et al. 2007) were processed to determine dietary species composition, emergent patterns in feeding, and links to the benthos as part of an overall program to examine the spatial utilization of fish habitat.

The stomachs of 190 juvenile haddock (mean length 15.7 ± 4.72 cm) were collected from two study areas on each of Emerald Bank, Western Bank and Sable Island Bank. Overall, the juvenile haddock had a broad prey field with 142 taxa identified. The average number of items/stomach was 71.04 ± 224.78 with a range of 1–2098. Five species, two amphipods, two cumaceans and a sand shrimp, accounted for 50% of total prey abundance and 20 species accounted for 99% of total prey abundance. Based on the state of the prey in the stomachs we believe that most of the taxa were consumed within 12 hours of capture. All prey were benthic species with one being hyperbenthic and the others epibenthic - confirming the close dependence of this fish size class with the bottom.

Despite an overall similarity in prey items, there were highly significant differences in diet composition between the preferred and non-preferred sites on each bank (ANOSIM R=0.508 All Sites; 0.218 Emerald Bank; 0.331 Western Bank; 0.664 Sable Island Bank; P=0.001) and between banks (ANOSIM R=0.458; P=0.001), as determined from a Bray-Curtis similarity matrix based on species presence/absence. There were also significant differences in the relative abundance and biomass of the dietary species between the six sites and between preferred and non-preferred sites within each bank (ANOSIM P<0.001 except for relative biomass on Western Bank where P < 0.004). For all sites, each of the top species were consumed by more than 50% of the fish at that site although average similarity in diet ranged from 26% to 58%, indicating individual foraging is a major driver in reducing average similarity within sites (Table 1). At all sites amphipods and/or cumaceans emerged as important prey taxa, with bivalve molluscs also being important at the Sable Island Bank sites.

Time of Day (dawn, day, dusk, night) could only be tested at 4 sites (Emerald Bank preferred and non-preferred, Sable Island non-preferred and Western preferred), and there was no significant difference in diet composition. Similarly, there was no significant difference between fish caught in different hauls within sites, suggesting that scavenging was not a factor.

A column-centered principle components analyses (PCA) was performed on the 20 taxa accounting for greater than 1% of total prey abundance (Fig. 1). Abundance of prey was converted to relative proportion so that the total abundance of prey per fish equalled one. The first three axes explained approximately 50% of the variance in the data, with ~30% explained by axes 1 and 2. This multivariate analysis showed a very interesting pattern. The individual feeding habits of the fish on Western and Sable Island Bank sites were similar to one another in the relative proportions of prey taxa. However, on Emerald Bank the fish had very strong and individual feeding behaviours. At the preferred site individuals deviated from the typical diet in selecting for the amphipod *Ericthonius fasciatus*, while at the non-preferred site fish showed selection for either *E. fasciatus* or the cumacean *Petalosarsia declivis*, with only a few fish preying on both. *E. fasciatus* is a common species in the benthos but *P. declivis* could be considered relatively rare (Fig. 1).

Juvenile cod (N = 144; mean fish length = 19.4 ± 3.92 cm) had a narrower diet than the juvenile haddock (88 prey items identified, all benthic) and fewer items per stomach (20.4 ± 22.64; range 1–163 items), despite generally being caught in the same hauls as the haddock and, therefore, likely to encounter the same benthic species during foraging. However, cod showed the same pattern with significant differences in diet composition (diversity, abundance, and biomass) between banks and between areas within banks, except for the preferred and non-preferred areas on Emerald Bank where the diets were not significantly different. The column-centered PCA, performed as for the juvenile haddock, showed much stronger individual feeding behaviour on all banks and no suggestion of a typical diet.

Biological traits analyses of the top 20 haddock prey taxa accounting for 85% of overall abundance against six biological traits showed that more than 50% of these taxa were non-tube-dwelling, surface deposit feeding, epifaunal, crawling species with moderate mobility. The ordination of the fish stomach contents with the biological traits (co-inertia analyses R=0.433; P=0.01) indicated significant differences in the traits of the species consumed between banks. Most of this difference was attributed to feeding on sessile infaunal species on Sable Island Bank; traits not strongly represented in the diets of fish on the other banks.

These analyses of the stomach contents of the juvenile haddock and cod illustrate a strong link to the benthos as evidenced by the lack of any pelagic species in the diets. Multivariate analyses suggest that the juvenile haddock on Emerald Bank and the juvenile cod also show strong individual selection for particular prey. The stomach contents were significantly different between sites within banks. In order to examine whether this difference was simply because the benthic species available to the fish differed at this scale, Bray-Curtis matrices were constructed on the presence/absence, abundance and biomass of benthic taxa sampled using a bottom grab at ten locations within each site (N=60) in 2003. In all, 336 taxa from 12 phyla were identified with Annelida (primarily polychaetes), Arthropoda (primarily amphipods) and Mollusca (both bivalves and gastropods) being the most specious. One hundred eighty-four were epifaunal species, 85 were infaunal and 87 lived at the sediment-water interface. As for

the analyses of fish stomachs, the benthic species composition was significantly different between banks (ANOSIM $P < 0.001$). However, the only significant differences in the metrics observed between sites occurred on Sable Island Bank. We have attributed this difference to the presence of gravel substrates at the preferred site while the non-preferred site was entirely sand (Fader 2007). Therefore, we concluded that the differences in the stomach contents of the juvenile haddock and cod were not primarily due to differences in prey availability with the above possible exception (accepting that small-scale patchiness in prey distribution and a highly localized foraging range of the fish could still be operating).

To further examine the foraging behaviour of the juvenile fish we took advantage of the fact that for many benthic invertebrate species there is a functional relationship with the substrate. For example, *Pectinaria* constructs tubes out of sand grains that are selected by size. This species is highly selective for fine sand habitats. Other species, such as certain anemones, require hard substrate for attachment. Using the literature to establish these functional relationships, prey taxa were classified as being associated with sands and muds, gravels, or as not having a strong functional relationship with the substrate. Using only the first two categories, matched-pair t-tests were performed on the stomachs of individual fish within each site. These results showed that juvenile haddock and cod ate significantly more (number of species, abundance and biomass) of prey associated with sand habitats than of prey associated with gravel. The only exceptions were on the preferred site on Emerald Bank where the haddock ate significantly more (abundance) species associated with gravel, a higher diversity of sand-associated taxa, with no significant difference in biomass. Cod did not prey on significantly more (abundance or biomass) species from either substrate habitat at this site. Further χ^2 tests of the proportion of sand-associated species in the stomachs versus the proportion of sand at the site were highly significant ($P < 0.0001$) overall and between sites on each bank for both species (except for haddock feeding between sites on Western Bank). Therefore, the fish were not showing a high selection for sand-associated species simply because there was more sand habitat.

In conclusion, juvenile haddock and cod have strong dietary links to the benthos. There is strong evidence for foraging over sand substrate and for this behaviour to be selective. These results are preliminary, pending the inclusion of the 2005 benthic grab sample data which is not yet available. These data may alter our view on the degree to which selection occurs, however, the analyses of the diets themselves are not expected to change substantially.

Table 1. The top three prey taxa observed at each site based on the presence/absence of the taxon in the stomachs of juvenile haddock. The average similarity of diets based on the Bray-Curtis metric is listed. The average frequency represents the proportion of fish consuming the taxon and the cumulative % frequency indicates the contribution to the total similarity among diets.

Dominant Prey Taxa	Average Frequency	Cumulative % Frequency
Emerald Bank Preferred (N = 37 stomachs)		
Average similarity: 25.95%		
Dyopedos monacanthus (Amphipod)	0.73	33.05
Unciola irrorata (Amphipod)	0.54	54.26
Ericthonius fasciatus (Amphipod)	0.57	72.02
Emerald Bank Non-preferred (N = 65 stomachs)		
Average similarity: 29.98%		
Petalosarsia declivis (Cumacean)	0.74	20.91
Ericthonius fasciatus (Amphipod)	0.58	33.38
Erythrops erythropthalma (Mysid)	0.55	45.23
Western Bank Preferred (N = 29 stomachs)		
Average similarity: 35.58%		
Protomedeia fasciata (Amphipod)	0.86	12.83
Unciola irrorata (Amphipod)	0.83	24.82
Ampharete sp. A (Polychaete)	0.79	35.57
Western Bank Non-preferred (N = 7 stomachs)		
Average similarity: 58.11%		
Crangon septemspinosa (Decapod- Shrimp)	1.00	16.03
Pleusymtes glaber (Amphipod)	1.00	32.06
Monoculodes sp. A (Amphipod)	1.00	48.09
Sable Island Bank Preferred (N = 31 stomachs)		
Average similarity: 51.33%		
Vaunthompsonia sp. A (Cumacean)	0.94	17.73
Crangon septemspinosa (Decapod)	0.90	35.14
Ensis directus (Bivalve - Clam)	0.87	50.96
Sable Island Bank Non-preferred (N = 21 stomachs)		
Average similarity: 40.15%		
Lamprops sp. B (Cumacean)	0.90	15.24
Monoculodes sp. A (Amphipod)	0.81	26.50
Serripes groenlandicus (Bivalve - Clam)	0.71	34.62

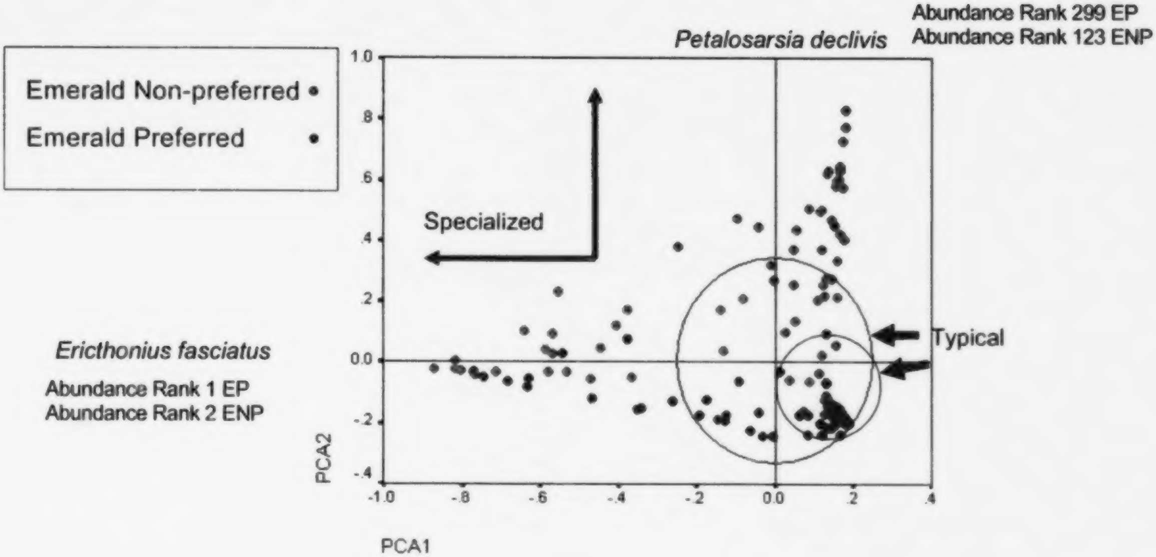

Figure 1. Biplot presentation of diet composition of individual juvenile haddock displayed in a column-centered principle components analysis (PCA1 and PCA2) of the abundance of 20 prey taxa (accounting for greater than 1% of total abundance). Fish from the six study sites are separately coloured. Fish from the non-preferred and preferred sites on Western Bank are indicated by pink and yellow-filled circles and those from Sable Island Bank by dark- and light-blue-filled cirlces respectively. The fish from Emerald Bank are identified in the legend. The species contributing most to the variance of each axis are listed along with their abundance ranking in the benthic data set. Circles indicate typical diets with the smaller circle highlighting typical diets for Western and Sable Island Banks and the larger circle all three banks. The fish on Emerald Bank show stronger specialization (i.e. selection for particular prey items).

EPIFAUNAL COMMUNITIES ON WESTERN BANK

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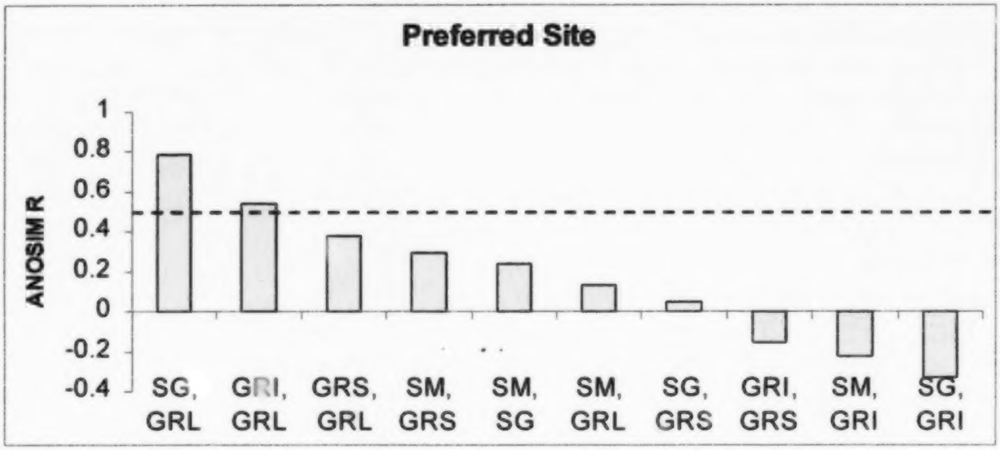
An objective of the spatial utilization of benthic habitats by demersal fish project (see Gordon 2007) was to describe epifaunal communities at the study sites and relate these to the physical habitat. Epifauna superimpose biological structure onto the underlying physical structure (e.g. surficial geology) and, when combined, provide a more complete picture of the habitat. Increasingly, it is recognized that combining physical and biological habitat components in a geographical information system (GIS) format is a powerful tool for addressing questions related to spatial and temporal relationships between fish and their habitat. The following study focused on Western Bank which is known to have a diverse physical habitat. Questions that were addressed were: (1) Do patterns of epifaunal species composition show significant day-night variation? (2) Are specific geological strata characterized by distinct epibenthic species associations? (3) Can information extracted from photographs provide insight into fish distributions in terms of diet and associations with biological structures?

Digital still colour photographs were taken at 30 second intervals during the course of Towcam video surveys along two 5 km transects through the preferred and non-preferred detailed study areas. Although variable, altitude was approximately 2.5 m and the area of individual photographs was 1.5 m^2. Transects were repeated day and night. During the course of fieldwork sidescan sonar surveys were conducted within the study areas for purposes of physical characterization of the surficial geology. In the lab, the entire detailed study area (5 km x 1 km) was classified into polygons representing interpreted sediment units (ISU) or geological classes based on surficial geology and seabed morphology (Fader 2007). Photographs were processed blindly (i.e. without knowledge of location or time) using Adobe Photoshop software. All visible organisms were recorded as presence-absence. Subsequently, the number of taxa was reduced by excluding those organisms known to be infaunal (e.g. burrowing anemones and tube-dwelling polychaetes) but had been recorded due to exposed tentacles. Using ArcView GIS, photographs were classified according to site (preferred, non-preferred), time (day, night) and ISU. Photographs were binned prior to analysis. The rationale for this was that there were too many individual photographs for practical display purposes. A binning number of five was selected and, while arbitrary, ensured that under-represented ISU's had sufficient replication. Prior to binning, photographs were randomly sorted within each site-time-ISU combination to control for any potential spatial autocorrelation. The 'new' dataset incorporated a quantitative measure of frequency of occurrence of each taxon. Multivariate analyses were carried out on the entire invertebrate dataset using PRIMER-E software (Clarke and Gorley 2006).

A total of 900 photographs were processed. There was sufficient replication of binned photographs to analyze only five of up to nine ISU's within each site. Two of the ISU categories were common to both sites (sand with megaripples, gravel ripple short wavelength). ISU's ranged in coarseness from relatively flat sand to gravel with boulders. Sand and sand with megaripples dominated at each site based on the interpreted sidescan imagery. A total of 59 epifaunal taxa were recorded. Taxonomic resolution ranged from unidentified to the level of species with Porifera having the poorest resolution and Mollusca and Echinodermata the highest. Two-dimensional non-metric multi-dimensional scaling (MDS) showed only subtle, non-significant differences in epifaunal species composition between day and night and night survey data were selected for further analyses. Based on MDS and ANOSIM analyses, individual ISU's were poorly characterized by their epifaunal species composition at the preferred site and strongly characterized at the non-preferred site. Using a cut-off ANOSIM R value of 0.5 only 2 of 10 possible ISU epifaunal species composition pair wise comparisons were distinctly different at the preferred site compared with 8 of 10 at the non-preferred site (Fig. 1). The explanation for the differences between the two sites lies in the occurrence of the two coarsest sediment clasts (gravel lag and gravel with boulders) at the non-preferred site only. While most of the other ISU's were comprised of finer sediments (i.e. sand) dominated by the echinoderms *Echinarachnius parma*, *Asterias* sp., and *Cucumaria frondosa*, gravel lag and gravel with boulder ISU's comprised relatively large and stable clasts (cobble and boulder) with an associated diverse community of sessile (e.g. Porifera, Hydrozoa, Cnidaria) and mobile taxa. Average species richness on these two coarse ISU's was three times greater than on the finer sediments which accounted for the distinct differences in epifaunal species composition between ISU's between the two sites. This result corroborates ecological understanding of increasing species richness with sediment coarseness and stability. Too few photographs had records of fish to permit investigation of associations between fish and epifauna and fish and ISU's. Out of 900 photographs, four showed haddock while two showed cod. Photographs taken over long transects on Western Bank were ineffective in studying associations between fish and biological structures at small spatial scales. Factors include spatial patterns of fish distribution combined with frequency of photographs and image size. Epifauna taxa identified as haddock and cod prey items (see Kenchington 2007) made a minor contribution to total benthic prey consumption (majority <1% of total prey abundance). Other taxa, not resolved in the photographs (e.g. too small and/or mobile to observe), were more important in the diet of these fish.



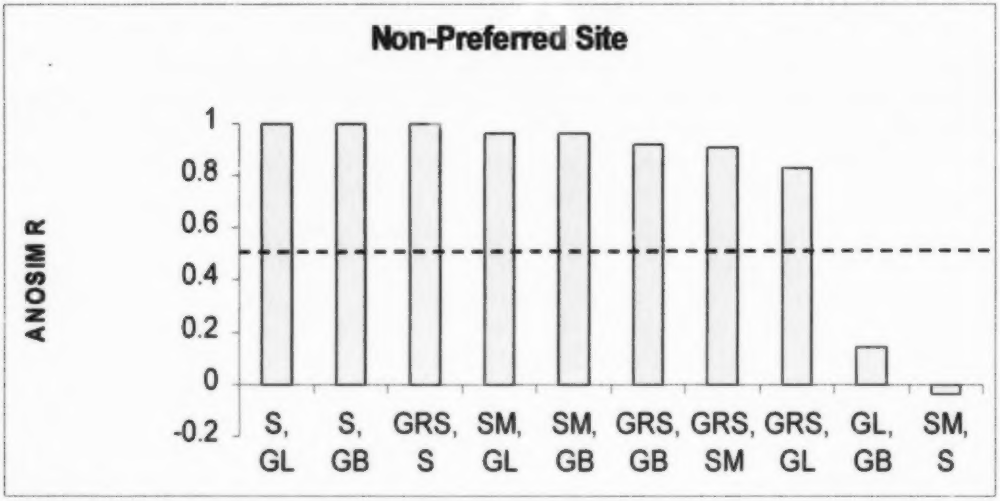


Figure 1. ISU pair-wise comparisons for the preferred and non-preferred sites. Pair-wise comparisons falling below the dashed line (ANOSIM R=0.5) are not distinctly different. SM-sand with megaripples, S-sand, SG-sand/sandy-gravel, SB-sand with boulders, GRL-gravel ripple long wavelength, GRS-gravel ripple short wavelength, GRI-gravel ripple incised, GL-gravel lag, GB-gravel with boulders.

HABITAT SUITABILITY CRITERIA FOR JUVENILE HADDOCK AND ATLANTIC COD ON THE SCOTIAN SHELF

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Habitat suitability criteria (HSC) were used to quantify the relationships between fish and the physical characteristics, such as depth and substrate that describe their habitat. HSC are expressed as the ratio of habitat utilization, as determined by relative abundance in each habitat, to the amounts of each habitat available. The primary goal in this study was to develop and evaluate substrate HSC using acoustic and video fish sampling techniques to measure the distributions of juvenile fish over two surficial geology classification schemes at different study sites. The first geological classification was based on an interpretation of the sidescan mosaics (Fader 2007b). The second substrate class was based on multibeam backscatter trained to recognize up to four of the interpretted classes based on the sidescan data. The trained data set could then be used to predict surficial substrate for the entire multibeam data set.

The project collected data on three regions of the Scotian Shelf: Emerald Bank, Western Bank, and Sable Island Bank. On each of these banks, two large 10 km x 10 km areas were selected representing preferred and non-preferred habitats based on historical fish distributions (Anderson et al. 2005). Within each of these 100 km^2 areas, smaller 5 km^2 study areas were selected for detailed analyses. All the HSC calculations in this study were based on data collected in the preferred and non-preferred 5 km^2 study areas of Western Bank.

In 2002 sidescan mosaics were generated for the study areas which, along with sediment grabs and photographs were interpreted and classified into geological units (Fader 2007). The interpretations resulted in seven different substrate classes for the preferred area and eight for non-preferred area. These interpretations served as the first description of surficial substrates for HSC estimation. In 2005, a multibeam survey collected data that were processed to calculate bathymetry and backscatter images (Courtney 2007). The interpreted sidescan classification was then used to evaluate the distributions of the backscatter intensities under each interpreted class. This analysis revealed that the multibeam data was unable to resolve all of the classes in the sidescan interpretation. Subsequently, the sidescan classification schemes were collapsed into four substrate types that were discernable in the multibeam backscatter. Similarly, normal incidence and sidescan sonar backscatter data detected four acoustic classes for these areas (Courtney et al. 2005). This new classification scheme was used to create a supervised classification of the acoustic backscatter intensity which served as the second substrate classification scheme used in the HSC analysis.

Fish abundance, as presence/absence data, was determined day and night using two separate sampling technologies: normal incidence single beam echosounder and a towed video camera system. Haddock and Atlantic cod could not be distinguished for either system; therefore, observations were combined into total gadoid abundance. Trawling revealed that haddock numerically dominated over Atlantic cod by a factor of 24:1 in the preferred areas of all three banks and by 58:1 in the non-preferred area on Emerald Bank (Dalley et al. 2007). In contrast, cod dominated over haddock by a factor of 2:1 in the non-preferred areas of Western Bank and Sable Island Bank (op. cit.). Therefore, our estimates of HSC primarily relate to haddock in all of the preferred areas and the non-preferred area on Emerald Bank and, to a lesser extent, relate to cod in the non-preferred areas on Western Bank and Sable Island Bank. The acoustic fish data were integrated to average of 8.5 m along track with an average across track width of 7 m. The towed video system data was also aggregated along track to 5 m intervals and had an average across track width of 3 m.

A Geographic Information System (GIS) analysis was used to determine fish habitat utilization (HSC) in relation to the different substrate classes. Fish data were aggregated to calculate the proportions of observed fish found over each substrate class. Habitat availability was calculated as the area of the seafloor under the footprint of the sampling equipment, whether fish were observed or not. The sampling transects were buffered to represent the across track distance which were then used to extract the area of the seafloor sampled. Area calculations were performed on the resulting subset and the proportions of each substrate class observed were calculated. These analyses were performed using both the interpreted sidescan and the supervised backscatter substrate classifications. HSC were created by calculating the ratios of the habitat utilization to availability for both sampling methods, substrate classifications and study sites.

Two decision rules were implemented to aid in interpreting the calculated HSC values for Western Bank. The first was to emphasize in our interpretations only those substrate classes that comprised more than 10% of the total available habitat. On Western Bank these predominant substrate classes were sand mega-ripples, gravel ripples, gravel with boulders and sand. Second, HSC ratios that varied by 10% or more, ≤0.9 to ≥1.1, were considered to indicate positive and negative selection, respectively. Ratios that were within 10% of 1:1 were considered as neutral selection.

In the preferred area on Western Bank the HSC for the acoustic and video fish data agreed for both day and night and both substrate classification schemes (Table 1). The HSC showed a neutral to negative selection for sand mega-ripples and a positive to neutral selection for gravel ripples. In the non-preferred area the acoustic fish data showed the same habitat selection as the preferred area; neutral to negative selection for the sand substrates and neutral to positive selection for the gravel substrates. The video fish sampling technique produced somewhat different result in the non-preferred area, showing a positive to neutral selection for the sands and a negative to neutral selection for the gravels. This could possibly be explained by an under estimation of fish in the gravel sites. The altimetry data for the towed video system demonstrated that the

system was towed approximately 0.25 to 0.4 m higher over the gravel-boulder sites than when over the other substrates. This change in elevation could have resulted in an under estimation of fish within that substrate class which would explain the anomalous result. Overall, we conclude that juvenile haddock and Atlantic cod selected gravel habitats over the sandy substrates both day and night for both study areas. In addition, there is an apparent selection for ripple habitats which suggests that small scale bathymetric relief is an important fish habitat attribute independent of substrate composition.

Table 1. Habitat suitability criteria (HSC) for the Western Bank preferred study area. Colours represent habitat selection: red–negative selection; yellow–neutral selection; green–positive selection.

Interpreted Sidescan	Acoustic Day	Acoustic Night	Video Day	Video Night
Sand Mega-ripples	1.0	0.9	0.9	0.8
Gravel Ripple Short	1.2	1.3	1.4	1.0
Gravel Ripple Long	0.9	1.2	1.0	1.3
Supervised Class				
Sand Mega-ripples	0.9	0.9	1.0	0.9
Gravel Ripples	1.3	1.4	1.1	1.2

Table 2. Habitat suitability criteria (HSC) for the Western Bank non-preferred study area. Colours represent habitat selection: red–negative selection; yellow–neutral selection; green–positive selection.

Interpreted Sidescan	Acoustic Day	Acoustic NNight	Video Day	Video Night
Sand Mega-ripples	0.9	1.1	1.0	1.2
Sand	1.0	0.8	1.6	1.3
Gravel w/Boulders	1.1	1.2	0.9	0.5
Supervised Class				
Sand Mega-ripples	0.8	1.1	1.0	1.2
Sand-Sand w/Boulders	1.1	0.8	1.5	1.2
Gravel w/Boulders	1.1	1.1	0.7	0.7

Table 1. Habitat suitability criteria (HSC) for the Western Bank preferred study area. Colours represent habitat selection: red–negative selection; yellow–neutral selection; green–positive selection.

Interpreted Sidescan	Acoustic Day	Acoustic Night	Video Day	Video Night
Sand Mega-ripples	1.0	0.9	0.9	[illegible]
Gravel Ripple Short	[illegible]	[illegible]	[illegible]	1.0
Gravel Ripple Long	0.9	[illegible]	1.0	[illegible]
Supervised Class				
Sand Mega-ripples	0.9	[illegible]	1.0	[illegible]
Gravel Ripples	1.3	[illegible]	1.1	[illegible]

Table 2. Habitat suitability criteria (HSC) for the Western Bank non-preferred study area. Colours represent habitat selection: red–negative selection; yellow–neutral selection; green–positive selection.

Interpreted Sidescan	Acoustic Day	Acoustic NNight	Video Day	Video Night
Sand Mega-ripples	0.9	1.1	1.0	[illegible]
Sand	1.0	[illegible]	[illegible]	[illegible]
Gravel w/Boulders	1.1	[illegible]	0.9	[illegible]
Supervised Class				
Sand Mega-ripples	0.8	[illegible]	1.0	[illegible]
Sand-Sand w/Boulders	1.1	[illegible]	1.5	[illegible]
Gravel w/Boulders	1.1	[illegible]	0.7	[illegible]

NEW INSIGHTS INTO THE DEFINITION OF PREFERRED AND NON-PREFERRED SEABED HABITATS FOR DEMERSAL FISH

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There are a number of underlying assumptions that are central to defining fish habitats in this study (Table 1). In some cases these assumptions can be tested based on data collected in this study. In other cases, such as predation mortality, it is not possible to test our assumption at this time. In addition, while we can measure what juvenile haddock and Atlantic cod ate during our study we have no knowledge of how these diets might have varied with time, either within the summer–autumn period or among years. Further, we have no knowledge on how these juvenile fish foraged over hours, days and weeks. It is understood that habitat and the spatial scales at which it operates must be linked to life processes such as growth and survival. However, that was beyond the scope of our research program. On the other hand, we are guided by work in terrestrial systems. There we learn that it is important to first develop your map of available habitats and then, with this map in hand, study the effects of the different habitats on life processes (Gardner et al. 2001).

A significant data set has been collected across a range of spatial scales from meters to kilometers on three different fishing banks that vary in size from 1,500 km^2 to 13,000 km^2. The individual data sets sampled the physical and biological nature of the seabed as well as fish abundance and distribution. These data sets were designed to develop a robust definition of fish habitat and, in turn, to make testable predictions based on this definition (Fig. 1). The historical data suggested that the spatial scale of preferred and non-preferred areas on the Scotian Shelf was 100 km^2, or less (Anderson et al. 2005). Logistically, it was not possible to sample all habitat variables at this spatial scale. Therefore, one of our first tasks was to compare measures made within our 5 km^2 detailed study areas to similar measures at 100 km^2. Bathymetric relief was greater and similar structures occurred across smaller spatial scales within the preferred areas on all three banks (Anderson et al. 2005). Comparison of bathymetric relief within the 5 km^2 detailed study areas were the same as those made in the larger 100 km^2 areas (Anderson et al. 2007a, Fig. 2). This demonstrates that the spatial scales of fish habitat may be on the order of 100 km^2. A similar relationship was found for a much simpler measure, namely the range of one meter bathymetric contours within each area at each spatial scale.

Our measurements of fish abundance confirmed the historical distributions where preferred areas contained more haddock (Dalley et al. 2007). The differences in haddock abundances between preferred and non-preferred areas were most apparent on Sable Island Bank and Western Bank. These results were confirmed by both acoustic and video based measurements of fish abundance (Anderson et al. 2007b). In 2002, haddock were dominated by the 1999 year-class as three year old fish, the largest year-class on record. Therefore, our measurements occurred during a period when we would expect density dependent processes to be most evident. The distribution of haddock was consistent with density dependent selection of habitat (Fretwell and Lucas 1970). Comparison of Atlantic cod abundance to haddock demonstrated that either Atlantic cod did not select for the preferred areas or that there was competitive exclusion by haddock from these areas. Benthic communities did not differ between preferred and non-preferred areas whereas the diets of juvenile haddock and Atlantic cod did, inferring site specific prey selection (Kenchington et al. 2007). We conclude that significant life history processes of haddock and Atlantic cod occurred across spatial scales of hundreds of meters to kilometers within each of the banks measured in this study.

The surficial geology was dominated by sand (60-100%) compared to gravel (0-40%) habitats in all areas. However, the arrangements of these substrates differed between the preferred and non-preferred areas on Western Bank and Sable Island Bank (Fader 2007). The preferred areas were characterized by smaller patches of both sand and gravel compared to the non-preferred areas. In addition, the proportion of the seabed containing ripples was greater in the non-preferred areas. Combined, these results indicate that the surficial geological habitats in the preferred areas were smaller and more rugged with more complex boundaries between the classified areas. A similar comparison cannot be made for Emerald Bank due to the absence of an interpretation in the preferred area (see Anderson and Gordon 2007). The distributions of haddock and cod within the preferred and non-preferred areas on Western Bank and Sable Island Bank demonstrate a tendency to select gravel habitats while there was neutral selection for sand habitats (Ollerhead and Anderson 2007). The juvenile diets were dominated by benthic prey that tend to occur in sand (Kenchington et al. 2007). This apparent mis-match, where fish tend to select gravel habitats while their prey were dominated by sand-loving prey can be explained in two ways. First, gravel habitats often occurred with significant amounts of sand in which sand-loving prey could live. Second, fish could forage from gravel to sand habitats and return to gravel habitats for digestion. Experimental research on juvenile cod demonstrated they preferred sand habitats in the absence of predation risk but selected cobble and macroalgae habitats in the presence of a predator (Gotceitas and Brown 1995; Fraser et al. 1996). We hypothesize that juvenile haddock and Atlantic cod on the Scotian Shelf prefer gravel habitats that decrease their predation risk but forage over sand. In this context, complex boundaries between sand and gravel habitats will reduce mortality (predation risk) while maximizing growth (successful foraging).

Spatial scales of fish distribution and physical habitats appear to be on the range of 100s of meters to 1000s of meters (Anderson et al. 2005, 2007a, 2007c; Fader 2007). The scale of physical habitats was smaller in the preferred areas on Western Bank and Sable Island Bank. The scale of bathymetric relief de-correlation was on the order of 60 m to 95 m in the preferred areas compared to 120 m to 170 m in the non-preferred areas (Anderson et al. 2005). The surficial geological classes ranged from 25,400 m^2 to 76,600 m^2 in the preferred areas, which scales to simple linear distances of 160-280 m. In the non-preferred areas the geological classes ranged from 110,600 m^2 to 1,200,000 m^2, which scales to simple linear distances of 330-1100 m. The average spatial scales of fish density distribution ranged from 600 m to 1200 m with no apparent difference in spatial scaling between preferred and non-preferred areas (Anderson et al. 2007c). All of these distances represent the spatial scaling within the 5 km^2 study areas. Do these spatial scales apply to the larger 100 km^2 areas? The answer is yes, based on bathymetric measures of rugosity. Future work will examine the scaling up of surficial geological classes, acoustic surrogates of fish habitat and fish distributions from the 5 km^2 to the 100 km^2 scales.

Table 1. Assumptions of factors controlling habitat selection by juvenile haddock and Atlantic cod.

Assumption	Description
1.	Higher density occurs over preferred seabed habitats
2.	Density dependent distribution from preferred to non-preferred habitats
3.	Habitat selection primarily to avoid predation
4.	Habitat selection secondarily for prey availability
5.	Habitat provides protection by camouflage (crypsis) and cover (hide)

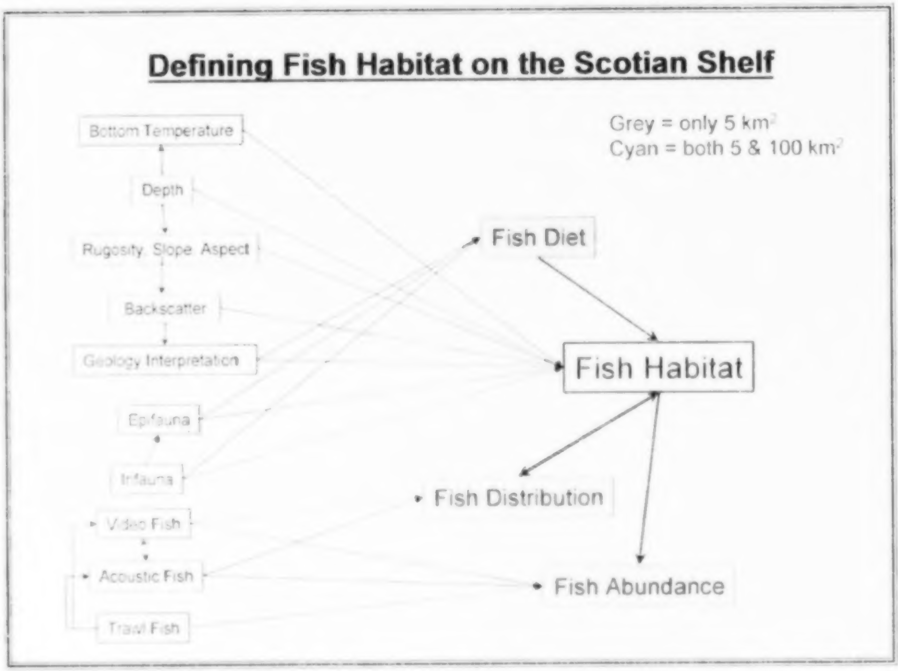
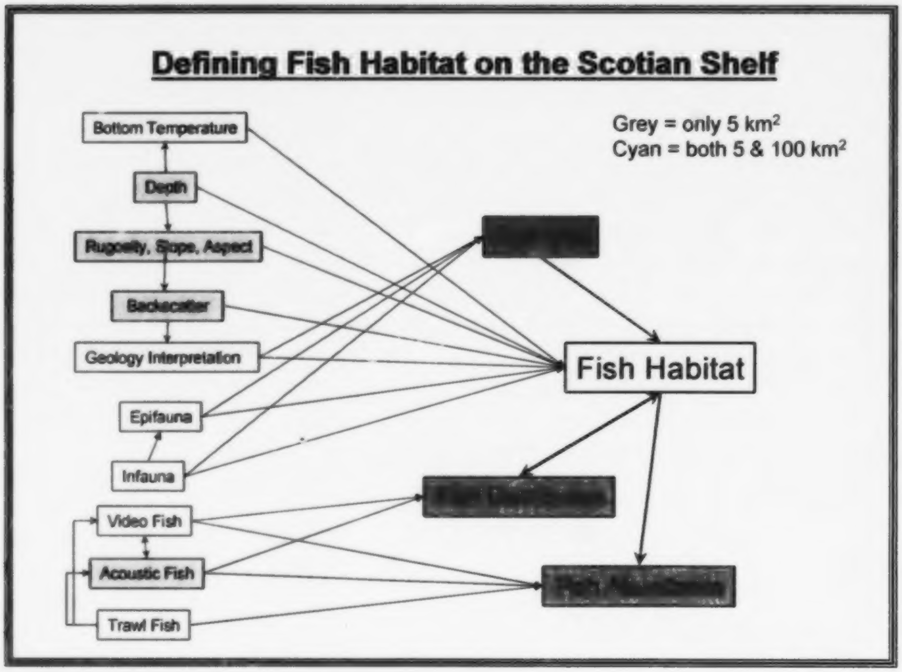


Figure 1. Schematic representation of data sets generated during this research program within the 100 km^2 and 5 km^2 study areas. The arrows indicate links between the individual data sets and the expected deliverables in terms of describing spatial distributions of haddock and Atlantic cod as well as their diets. Defining fish habitat can be done based on results generated from the individual and combined data sets.



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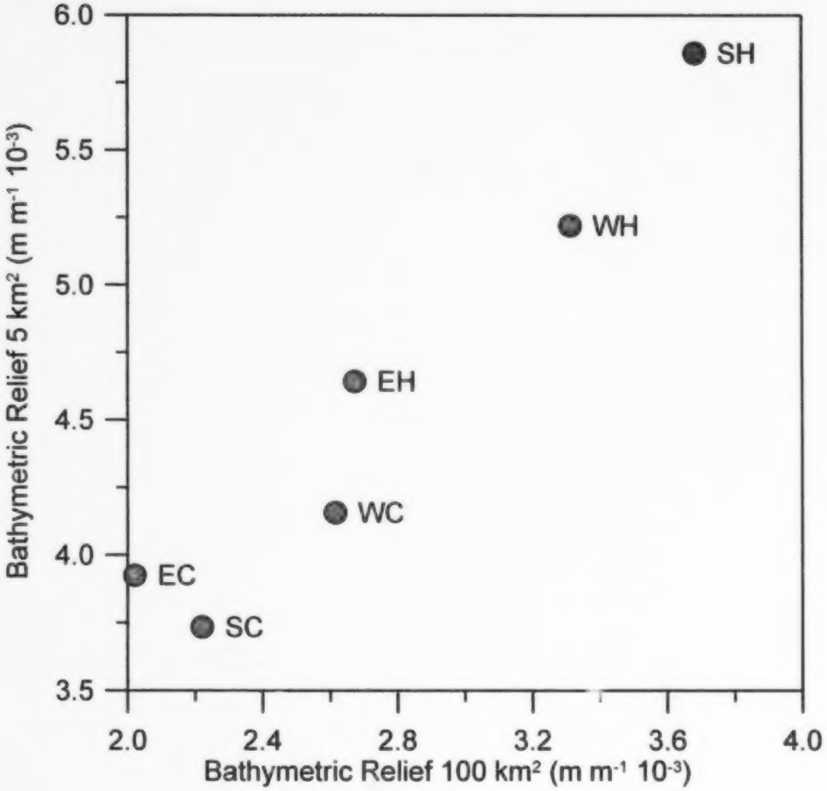

Figure 2. Bathymetric relief (m $m^{-1}10^{-3}$) measured within 100 km^2 study areas compared to more detailed measures of bathymetric relief within the smaller 5 km^2 areas.

LESSONS LEARNED

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This is the kind of research project that can only be done by a well-equipped government laboratory. It is long-term and multidisciplinary in nature, requires extensive engineering support to develop and operate field equipment, and needs major ship resources. This research can not be done by universities or industry. Nevertheless, numerous obstacles were encountered along the way which delayed progress. These included last minute cancellations of cruises due to fires, strikes and safety issues, insufficient technical support, other demands on the time of principal investigators, and retirement of key staff without replacement.

This project has demonstrated the value of a team approach when addressing such complex questions. Members were able to share experience and tools as well as debate new ideas and data interpretation. Communication has been very important both within the study team and outside. The frequent review and planning workshops involving the entire study team were crucial to the project. Communication within the study team was also assisted by working at sea together several weeks a year. Outside communication included keeping managers informed of progress, which assisted them in acquiring additional funding as needed, and briefing clients.

Careful data management is very important in a project such as this which collects such extensive and diverse data. This included setting up a proper structure for collecting, analyzing and archiving acoustic, imagery and sample data on habitat, fish and benthic organisms. It also included making the electronic data available to team members at both BIO and NAFC. The availability of GIS tools has been essential.

This project illustrates the many advantages that can accrue by involving more than one government department and DFO region. These are both political and scientific. It also illustrates the value of using more than one method to measure a particular variable be it physical habitat, fish or benthic communities. Each method has its own limitations and new insight and understanding can be obtained by comparing them. It also illustrates the advantages of comparing different study sites that were selected following set criteria.

This project could not have been conducted without the availability of adequate vessel support. At the moment, DFO does not have a vessel capable of conducting offshore multibeam surveys but we were fortunate to have been able to use the CFAV *Quest* at three of our study sites. Trawling was done by the CCGS *Alfred Needler*. Heavy use was made of the CCGS *Hudson* to carry out the sidescan, BioSonics,

Towcam, Videograb and IKU grab surveys. Her size, facilities and sea kindliness enabled the study team to operate on a 24 hour basis with very little down time due to weather. It is essential that she be replaced soon by a vessel of equal abilities.

The final lesson learned, which is not new, is that projects like this always take longer then expected.

FUTURE DIRECTIONS: MARCH 2007 AND BEYOND

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A road map of scientific products has been developed to guide the research teams in generating results at two levels (Fig. 1). The first level products (tier one) are considered the basic scientific results that can be generated by different groups of specialists. These products typically require specific expertise, such as taxonomic identification of benthos or understanding the physics of sound in seawater, to reliably generate the individual components based on data collected during the field work phase (T1-3, T1-6, T1-7, T1-8, T1-9, T1-10, T1-11, T1-13, T1-14, T1-15). In two instances comparative work has been done analyzing products from different measurement systems. The first was a comparison of sidescan sonar with normal incidence acoustics to evaluate their combined and individual capabilities to distinguish surficial geological features (T1-4, Courtney et al. 2005). The second was a comparison of acoustic and video derived fish data sets with each other and with reference to haddock and Atlantic cod captured by a bottom trawl (T1-12, Anderson et al. 2007). A review of the scientific literature was a starting point for our project (T1-2, Linehan 20) and further work has been extended to a review of how previous researchers have defined fish habitat (T1-2, Gilkinson and Anderson 2007). At the Tier 1 level, we have also outlined work that would relate to the scales of abiotic and biotic variables from meters to kilometers (T1-5). We determined that the scales at which physical and biological phenomena occur should be worked out independently before combining the data and looking for cross-correlations of spatial associations. As such this can be regarded as a group of independent results for surficial geology, bathymetric topology, fish and epibenthos. Finally, we have included our directed work on developing an integrated geo-referenced database and its integration into the ArcInfo GIS system (T1-1). Development and implementation of the database is critical to many of the Tier 1 and 2 analyses.

The second level of scientific products (Tier 2, Fig. 1) will result from an integration of Tier 1 data products into our definition of fish habitats (T2-1) and our evaluation of the ability of acoustic surrogates to detect and map juvenile fish habitats (T2-2). An important concept in our initial proposal was being able to predict fish habitats based on our acoustic surrogates (T2-3). Finally, we believe the knowledge learned in this project can be used to assist in the design of marine reserves that will enhance the yield to commercial fisheries for haddock and Atlantic cod (T2-4).

The project emphasized the collection of high resolution data across a perceived range of spatial scales. We accomplished most of the intended tasks with two notable exceptions. One is the absence of an interpretable sidescan sonar data mosaic for the Emerald Bank preferred 5 km^2 detailed study site. Suitable data were collected in 2002 and subsequently interpretted for surficial geology (Fader 2007). However, we determined that the site selected in the preferred area on Emerald Bank did not contrast sufficiently with the non-preferred site. Therefore, we selected a new 5 km^2 detailed study site which was sampled in 2003. Unfortunately, modifications made to the sidescan sonar system resulted in inferior data that could not be adequately interpretted for surficial geology. It would be prudent to collect sidescan sonar data at this site on an opportunistic basis. Second, is the absence of multibeam data for three of our six study areas: Sable Island Bank non-preferred, Emerald Bank preferred and non-preferred. Generally, it is held that research programs attempting to describe, classify and map marine habitats must begin with a high resolution multibeam image of the seabed. To that end, obtaining multibeam data at the remaining three sites is desirable.

A critical topic of discussion within our project, and among marine researchers, is the degree to which boundaries are continuous gradients between extremes (e.g. sand versus gravel, preferred versus non-preferred). With what degree of confidence can we draw a boundary between areas? Is the transitional area a boundary or a region in its own right? Western Bank would provide an ideal situation to test these questions. Our preferred and non-preferred areas were approximately 10 km apart. At this point we know the areas differed in surficial geological structure and seabed rugosity which can be measured by multibeam acoustics. Any future work should consider collecting multibeam data between these two areas as a high priority.

Ecological theory linking a species with its habitat ultimately is based on life processes. We believe that habitat selection by juvenile gadoids is primarily a function of predator avoidance during day light to reduce mortality and, secondarily, by adequate foraging at night time (dawn, dusk) to optimize growth. Our measures of haddock and Atlantic cod, and associating these with seabed habitat, was based primarily on abundance distributions observed at one point in time and then as a composite over time (Anderson et al. 2005, 2007; Dalley et al. 2007). However, the key processes are believed to be foraging and growth. We have studied fish diets (Kenchington et al. 2007) but not foraging. What is the hourly and daily gambit of a juvenile haddock or Atlantic cod on the shelf? We do not know. What is the degree of site fidelity for a foraging juvenile? We do not know. A major new research program could begin to address these issues using acoustic telemetry techniques (e.g. Cote et al. 2004).

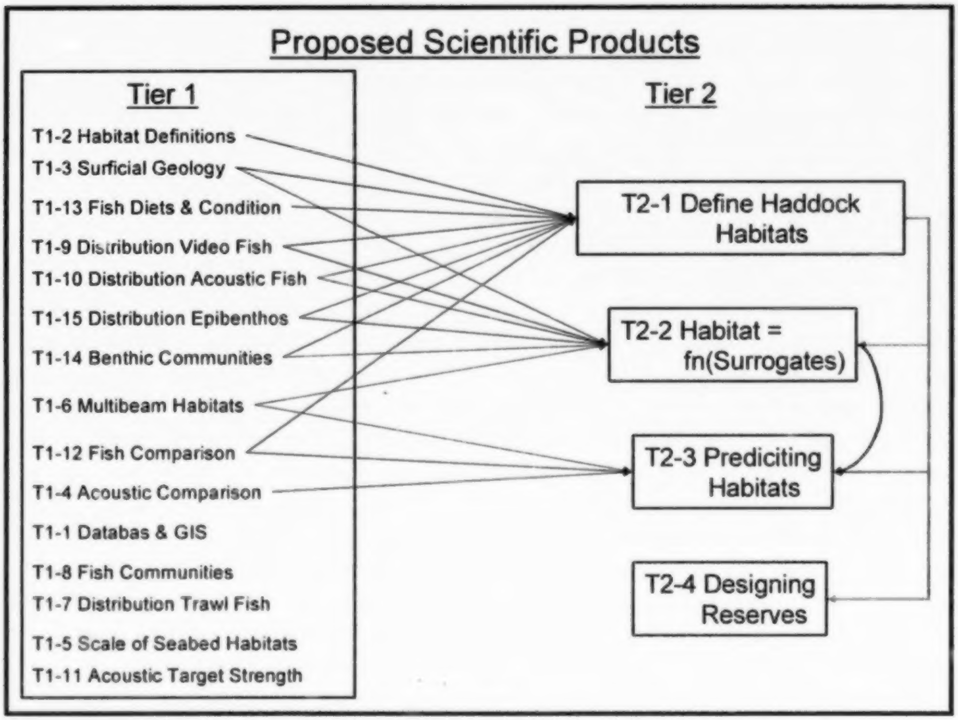

Figure 1. Schematic representation of basic scientific products (Tier 1) available to generate integrated scientific results (Tier 2). The numbers are for reference and the arrows indicate dependent relationships between products.

SPATIAL UTILIZATION OF BENTHIC HABITATS BY DEMERSAL FISH ON THE SCOTIAN SHELF

Project Critique

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Habitat quality models (HQM) are mathematical constructs that represent the relationship between indices of habitat quality (e.g. fish density, consumption, growth, survival, or reproduction) and specific environmental conditions that determine the degree of expression of such indices. HQM thereby serve two main objectives. First, they allow scientists to identify and map areas that possess environmental conditions that best foster some index that facilitate the persistence of a species. This is crucial to delineate areas that should be protected for conservation purposes. Second, they allow managers to forecast the effect of changes in environmental conditions on the quantity, the quality or the distribution of such areas. This is essential to predict the impact natural and anthropogenic perturbations may have on fish habitats. Hence, HQM constitute fundamental tools that render operational principles such as 'no net loss'. Population dynamic models and habitat quality models should be viewed as essential complements, biological and physical, of a same decision taking process.

The project led by Don Gordon (BIO) and John Anderson (NAFC) represents an outstanding opportunity to explore the process by which HQM should be developed. The quality of the researchers, the diversity of the skills available within this group, the spatial scale (the extent of the study area which encompasses a large fraction of the Scotian Shelf, the size of the sampling sites, the spatial resolution of the surveys), and the use of the best sampling gears currently available will significantly increase the scientific and technical expertise of this team but, most importantly, will serve as a prototype for other such studies that should be performed across the country and abroad. The project also benefits from solid background information about the geology, the oceanography and the biology of the study area. For instance, rather precise and detailed maps of fish capture rate (an index of fish density, and hence, of habitat quality) based on decades of research trawl sets performed over the complete Scotian Shelf are already available. These maps have two consequences. First, they force a more precise definition of the nature of the contribution of the project. Initiating a study to develop HQM may be perceived as questionable when one important product of HQM (a map of habitat quality) is available prior to the study. Consequently, the contribution of the project may not be to produce maps of habitat quality but to identify what makes different locations support different fish densities. But why is it important to identify what makes a good habitat for juvenile haddock on the Scotian Shelf? Are there expectations that predictions based on HQM may not fit the maps presently available? Where do

these expectations come from or where will they lead us? Are environmental conditions expected to change in the short or long term such that managers need to know how fish habitat quality may be affected by these changes? Second, the maps suggest that fish distribution is highly heterogeneous among parcels within the 10 km x 10 km sites referred to as preferred ('hot' sites with high fish densities) and non-preferred ('cold' sites with low fish densities). Yet, in many of the analyses presented during the Synthesis meeting, preferred and non-preferred sites were used as classifying variables. This sometimes led to unclear or debatable interpretations. In contrast with the expectation that parcels within preferred sites should always support more fish with better growth or larger sizes than parcels within non-preferred sites, fish density and size structure varied depending on the parcels of the preferred or non-preferred sites analyzed. As such, indices of habitat quality should be taken as a continuum and analyses should be performed with the assumption that any parcel of any site (preferred or unperformed) may belong anywhere along this continuum. This flexibility may be attained only by abandoning the concept of preferred ('hot') and non-preferred ('cold') sites at least during the analyses.

The development of HQM requires a spatial framework that insures that dependent (indices of habitat quality) and independent (environmental conditions) variables are collected at the same locations. The precise geographic positioning of the sampling parcels having dimensions at small as few to tens of meters is not a trivial exercise particularly at sea where sampling gears are mobile and are operated using long ropes attached to a mobile platform. The research team has done exceptionally well in this respect and this should allow them to develop relationships between the habitat quality indices observed at a series of parcels and the environmental conditions observed within these parcels. However, numerous hypotheses suggest the index of habitat quality assigned to a parcel is not only affected by the environmental conditions observed within this parcel but also by the spatial context of this parcel. The spatial context refers to the possibility that, for instance, a parcel covered with boulders within a) a large area of sand, b) a large area of boulder, or c) a patchy mosaic of sand a boulders may not all have the same ecological value as a fish habitat. The relative importance for HQM of environmental conditions found within and outside a parcel is currently unpredictable. Nevertheless, the data collected by the research team under various grain sizes may allow them to further explore this sort of hypothesis and eventually to improve the quality of their HQM.

The temporal framework of HQM is also a key determinant of the quality of HQM. Indices of habitat quality observed within a parcel are expected to vary among sampling sessions because of more or less well defined daily patterns of fish movements (it is understood that HQM may vary seasonally). Fish may momentarily (few hours or days) use a relatively poor habitat or briefly be absent from a good habitat. This situation is destined to negatively affect the predictive power of any HQM because it introduces noise in the relationship between indices of habitat quality and environmental conditions. There may be at least two approaches to minimize the impact of the temporal instability of habitat quality indices on HQM. First, visit each parcel on a number of occasions sufficient to obtain a temporally stable value of the mean habitat

quality index that should be assigned to parcels. Second, increase the size of the parcels such that the temporal variability of habitat quality indices is minimized. There are no *a priori* general rules to identify an optimal parcel size (small enough to provide a detailed representation of the spatial changes of habitat quality, large enough to minimize the temporal variability of habitat quality indices). I can only encourage the research team to explore the approaches listed above, define which performs best for juvenile haddock on the Scotian Shelf, and extract from their experience what may be useful under other conditions and species.

SPATIAL UTILIZATION OF BENTHIC HABITATS BY DEMERSAL FISH ON THE SCOTIAN SHELF

Project Critique

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The synthesis meeting provided a detailed overview of the project and presented the results and data analysis conducted to date. The following are my comments and suggestion based upon the information provided prior to the synthesis meeting and the data presented over the three day synthesis meeting. I have focused on the major strengths and weaknesses of the project, and provided specific comments on elements of the research which fall within my area of expertise in the field of benthic habitat mapping:

MAJOR PROJECT STRENGTHS

- The aims and objectives of the project are clearly defined, appropriate and extremely timely, and are of high importance and urgency for fisheries management.

- The research programme has collected an exceptional and unique data set from carefully selected study sites and clearly well-designed field programmes, despite logistical problems with field work outside of the control of the project team (i.e. cruise cancellations, etc.). A major strength of the research is its multidisciplinary nature, and a highly skilled research team with complementary areas of expertise was assembled to achieve this goal.

- The care and attention to the positional accuracy of the various data sets is to be highly commended. This is a crucial component of the project and was essential if the relationship between the variables was/is to be tested with any level of scientific rigour. This level of accuracy is rarely achieved in many similar studies of this nature, and the effort that has gone into this aspect of data collection in this project will allow precise correlation and spatial analysis of multiple data sets leading to excellent results with a high level of scientific confidence.

- Similarly, the care and attention to data management within the project is also exceptional. This will greatly facilitate further analysis of the data. I would

recommend that the project team considers and evaluates the use of the ESRI Marine Data Model for further spatial analysis of the data. This particular model may be suitable for manipulation of the spatial data sets and may prove to be a useful tool.

- The project is an excellent example of the benefits of the application of acoustic survey methodology, particularly the use of swathe acoustic systems (sidescan sonar, multibeam sonar), for studying and understanding benthic habitats. Without the remote acoustic survey data much of the biological data would be difficult to interpret. The project has affirmed that this type of spatial data is invaluable for accurate seafloor mapping and habitat conceptualization.

MAJOR PROJECT WEAKNESSES

- The concept of "hot" and "cold" study sites was not supported by the data that was presented during the meeting. Whilst this concept may have been valuable during the design and implementation of the field surveys, it appeared to be confusing for interpretation of the results. Both "hot" and "cold" sites were populated by cod and haddock and appeared to represent a gradient of conditions. I suggest that the concept of "hot" and "cold" areas is dropped, and that the data is analysed as six study areas encompassing a range (or gradient) of environmental conditions.

- The overall research objective often came across a little confused during several of the presentations. This is likely due to the multiple scales at which the research questions were being addressed. This is not surprising as the issue of what scale habitats should be studied, particularly for mobile species such as fish, is difficult to resolve. For example, should haddock habitat be studied at the scale of the whole shelf, whole bank, each study site, across each geological unit (ISU) within each study site, or within each geological unit (ISU) within each study site? This could be resolved by having a clear working definition of "fish habitat" and by breaking the study into two broad research questions:

1. Geographical population distributions? Is there habitat choice or are the broad distribution patterns a result of larval recruitment (i.e. a factor of water column characteristics/movement)?
2. Habitat associations – how are the fish using the various seabed features and geological units (ISUs) for different behavioural activities/life stages?

- Overly complicated statistics were often used for analysis of the data, and although simpler statistical routines may have been employed prior to the complex routines, evidence for this was not presented. I suggest that simpler multivariate statistical techniques are first applied to look for patterns and correlations within the wide range of data types that are available.

- The work was very much focused on analysis of the data in 2D. I would recommend that 3D (i.e. water column parameters and sub-surface geology), and 4D (Diurnal and seasonal) data sets, if available, are taken into consideration when analysing the data and interpreting the results.

OTHER COMMENTS AND SUGGESTIONS

Seafloor acoustics:

- Exciting advances in the analysis of the multibeam echosounder backscatter data were presented (i.e. use of the nadir anomaly for habitat discrimination). This is a very topical subject with several research teams around the world recognizing the potential importance of these data. Further analysis of this data, in conjunction with the biological data sets, should provide an excellent evaluation of its utility for habitat discrimination and mapping.

- Extraction of other metrics from the acoustic data sets, not presented during the meeting (e.g. rugosity, slope, mean backscatter etc.), may yield useful data layers for habitat mapping and modelling.

- Analysis of the MBES data using automated classification routines (e.g. QTC Multiview) may offer additional data layers which could prove useful for habitat discrimination/modelling.

Proxies for fish abundance:

- Based on the data that was presented, fish abundance appeared to be influenced by the spatial heterogeneity of the seafloor habitats, and the richness of seafloor habitats within the study areas.
- It should be possible to derive measures of complexity from boundary lengths between the different seabed types within each study area, and this may be a better "predictor" of fish abundance.

Linking data sets:

There was little evidence from the preliminary data presented that any of the data sets had been analysed in a spatial context to investigate the relationship between the various data sets. Analysis of the data is clearly ongoing and it is likely that this will be addressed in due course. However, the following suggestions may be useful for future analysis:

- Linking the epifaunal communities to the acoustic data sets – this has been addressed in a European context as part of the MESH project (Mapping

European Seabed Habitats: www.searchmesh.net). The project team may wish to look at the MESH guidelines and the possibility of adopting a hierarchical habitat classification approach based on the conspicuous/characterizing epifaunal species and the acoustic data sets.

- Linking the infaunal communities to the acoustic data sets – based on previous studies published in the scientific literature, and my own experience, this is unlikely to work particularly well. Problems posed by ubiquitous infaunal species and sediment gradients often result in "fuzzy" boundaries. Analysis of the infaunal data collected from discrete acoustic seabed types often fail to group into discrete assemblages following multivariate analysis (as was evident in the data presented during the meeting). In addition, particle distribution data was not collected at the time of infaunal sampling, making it extremely difficult to determine the relationship between surficial sediment characteristics and infauna. Care should therefore be taken when extrapolating these data to the fish stomach data.

- Linking the fish data to the acoustic data – at the scale of the seafloor acoustics (<0.5 m) the video fish and acoustic fish data will likely provide the best method for establishing habitat preference by the fish species. The important next stage is to look at the spatial relationship at this scale between fish abundance and seabed type (ISU).

Following further analysis of the data, I am confident that the project will contribute significantly to our knowledge of fish habitat and provide a valuable source of information for fisheries managers and scientists. I highly recommend that the results are published in the mainstream scientific literature upon completion of the data analysis.

SPATIAL UTILIZATION OF BENTHIC HABITATS BY DEMERSAL FISH ON THE SCOTIAN SHELF - CRITIQUE

Project Critique

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This research program set out to answer the following questions: (1) What is preferred seabed habitat for demersal fish, with focus on juvenile haddock? (2) What is the relative importance of physical and biological attributes? (3) What are the best methods for measuring preferred seabed habitat? (4) At what scales should preferred seabed habitat be measured? (5) Where is the preferred seabed habitat for juvenile haddock located on the Scotian Shelf? From a fisheries management perspective, it is important to define the functional relationships between fish and their habitats. In the United States, four levels of data are recognized that could be used to define Essential Fish Habitat: (I) Presence/absence, (II) Relative abundance data, (III) Habitat-specific growth, survival, and reproduction rates, and (IV) Habitat-specific production rates. Level III and IV data are needed to incorporate habitat into models of fish population dynamics, but in most areas, only level-II data are available.

Strengths of the Scotian Shelf project include the multi-year project organization, the multidisciplinary project team, instrument development and support, and data management. The sedimentary geology is clearly a primary determinant of fish habitat. The project demonstrated that sand and gravel habitats can be mapped a fine spatial scale. Four acoustic categories can be distinguished from the multibeam backscatter data. More sediment categories can be distinguished from the high-resolution side-scan sonar data. However, these sediment categories may not be the same ones that are apparent in the multibeam data, and it is not clear which sediment categories are biologically relevant. More work is required here. Sediment composition is a function of geological history, depth, and bottom currents. There is a gradient in depth and bottom currents from Emerald Bank (80 m), Western Bank (55 m), to Sable Bank (50 m). This physical gradient in sediment stability determines the benthic communities and may also be a more important determinant of fish habitat than the "hot" and "cold" areas on each bank that drove the sampling design. Subsequent data analyses should recognize this gradient.

A rich, geo-referenced database is now available. Some suggestions for statistical analysis are given here. In general, classical statistical tests should be employed first, and applied directly to the measured data when possible. A good measure of rugosity is required at different length scales. Fourier analysis of bathymetry transects could be used to determine the dominant length scales of

variability. The bathymetric data could then be high-pass filtered to remove the depth gradients, leaving a measure of rugosity. Data were presented on the frequencies of fish measured with acoustic and video observations. The proportion of zero frequencies scales inversely with mean abundance; a frequency distribution (e.g. negative binomial) can be fit to the data. If habitat selection is density dependent, one would expect the frequency distribution to become more uniform (less patchy) as density increases.

The method of "dynamic segmentation" could be used to classify the habitat types along the acoustic and video tracklines. To test whether fish distributions are associated with epifauna, the video fish data could be compared with epifauna observed in the Towcam photos. However, the photos cover too large an area to distinguish much epifauna. Standard prey-selection indices could be calculated from the fish diet data. The benthic fauna were classified based on biological traits (e.g. suspension/deposit feeders, reproductive mode). A visually intuitive way to test if these traits are important is to overlay them on the MDS (multi-dimensional scaling) ordinations of community composition.

My main recommendation for data analysis is to develop model-based definitions of fish habitat. Generalized additive models (GAMs) have been successfully applied in the Bering Sea and the New England coast. In the Scotian Shelf context, the response variables are the trawl, video, and acoustic fish data. The potential explanatory variables include: Depth, Rugosity, Temperature, Sediment type, Seabed current stress, Epifauna, Benthic community, Location (hot/cold). Ideally, the GAMs would predict fish density from the biologically meaningful variables, such that the location variables were no longer significant.

Habitat complexity appears to be an important attribute of fish habitat. The foraging arena hypothesis provides a useful paradigm to explain foraging behaviour at the hectare scale. Fish balance feeding opportunities on sand habitats with protection from predators on the gravel substrate. What are the predators of juvenile haddock? Testing this paradigm requires a measure of habitat complexity (e.g. the perimeter of habitat patches per unit area).

Not all of the research questions were answered in this project. The acoustic data suggest that some haddock occur off bottom, where they do not feed. Juvenile haddock in the water column could be transported considerable distances by tidal currents. Do juveniles choose their habitats or do they have habitat-specific survival? Can 2005 fish abundance data be predicted from models based on the 2002 and 2003 data?

SPATIAL UTILIZATION OF BENTHIC HABITATS BY DEMERSAL FISH ON THE SCOTIAN SHELF

PROJECT CRITIQUE

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The Scotian Shelf juvenile gadoid habitat project was reviewed from my perspective, a U.S. federal fisheries research scientist who has relevant experience in fish trophic ecology, ecosystem-based fisheries management, and essential fish habitat. As the final presenter among the review panel, I also note that those items that were common among the review panelists were coordinated but from highly different disciplinary perspectives. As such, those items which were repeated among us should be particularly noted.

PROJECT STRENGTHS: SCIENCE

Here and following I list the strengths and weaknesses of the project with respect to both science and organizational considerations. At the top of this list is a copious, rich, multidisciplinary data at multiple scales which is in many respects quite unique in the world. This lends towards an ability to address a wide range of questions at a wide range of scales. Further, the project design had careful, meticulous, and detailed methods. As such, the potential for elucidating insights into those factors that influence fish distribution, abundance, biomass, etc. is extant. These data sets represent a proverbial gold mine of data unlikely to be mined out anytime soon.

PROJECT STRENGTHS: ORGANIZATIONAL/LOGISTICS

Noting project strengths from an organizational perspective is often obvious upon inspection but is also often overlooked. Further, such positive considerations are usually not a trivial, assumed outcome in a highly interdisciplinary project such as this. Evident in our interactions with the project team was generally an attitude of excellent teamwork and camaraderie. That multiple regions and multiple agencies were involved is similarly not trivial nor to be overlooked. The interdisciplinary nature of the project was one of its key strengths. The project also afforded, and should continue to afford, career development opportunities for several scientists at DFO, NRCan and associated institutes.

Yet another key positive highlight was the infrastructure developed from this project that can be more broadly applied to other projects, regions, ecosystems, etc. In

particular, the database management efforts, the technology development, and the portable tools and approaches applied can serve as lessons for other elements of the respective organizations involved.

Finally, the project was delayed and took longer than expected. Delays on a project like this are not surprising. Yet the flexibility and persistence to carry the project through to completion of this phase was laudable. As someone who has led large, interdisciplinary projects, the exhibited commitment and perseverance despite unforeseen setbacks (ship fires, ship crew strikes, etc.) and people continuing after retirement are indicative of good project management.

PROJECT WEAKNESSES: SCIENCE

A fundamental issue remains- the project categorically needs to move away from the "hot" and "cold" analytical design; rather the data can be treated as gradients in a multi-variate sense.

Also fundamental is that the work still needs to link appropriate habitat metrics to fish metrics. I was expecting to see more of this analytical work and although certainly the data exist to elucidate this issue, it seemed like a core item that remained to be addressed. It is understandable given some of the delays noted above that this phase of the project has not yet happened. The project team should be strongly encouraged to bolster their efforts to this end.

Many of the conclusions presented did not match data as strongly as was stated in many of the presentations: e.g. hot-cold differences, synchrony among bottom mapping methodologies, acoustic species determinations, vertical distribution/migration etc. Similarly, some analyses were inappropriate or unnecessarily complex - e.g. survey abundances, acoustic abundances, fish diets, etc., when simpler, more standard approaches would be valuable to present. Perhaps I missed some of those approaches, yet some of the more routine, typical, and easier to interpret metrics and analytical approaches would have helped.

Another key item that was missing was an evaluation of utilization of habitat or diet or similar factors use (via selection/preference type of metrics) throughout the full range of observations.

PROJECT WEAKNESSES: ORGANIZATIONAL/LOGISTICS

If we're moving towards Ecosystem Approaches to Fisheries (EAF) Ecosystem Based Fisheries Management (EBFM), then it was striking that the project was effectively reductionist, emphasizing to a large extent the two species, haddock and cod. It remains unclear if these are the dominant economic and ecological species in this ecosystem. A multispecies, aggregate biomass, or community approach should be considered; certainly the data are extant to explore this.

At times the project presentations exhibited a seeming overemphasis on: the overwhelming variance/distinctions in all the data with less emphasis on noting major, repeatable patterns; and methods with less emphasis on addressing the major questions. Certainly this is reflective of the phase of the project, but it lent itself to a perception that in some respects (clearly and not entirely) that the external review seemed almost premature. I am not saying that the external review was not required nor that this was an incorrect time for it; rather I'd strongly encourage an emphasis on analytical work and perhaps another review after some of that analytical work has been executed.

A KEY QUESTION FOR DISCUSSION- WHAT DID WE LEARN THAT WE DIDN'T ALREADY KNOW THAT WILL INFLUENCE MANAGEMENT ADVICE IN THE CONTEXT OF:

- Fisheries
- Environmental Impacts (and Multiple sector ocean use)
- Delineating protected areas

Keeping this in mind will help with the prioritization of future endeavors. I am not stating that there was nothing learned at all nor am I stating that the work should not continue. Rather, in a management context, what is the best way to contextualize and prioritize future efforts?

ADDRESSING THE 5 CORE QUESTIONS

A short synopsis of the core questions for the project and my evaluation of their status.

1. Identifying preferred (or critical or essential or ...) fish habitat: had a start, but the question may ultimately be inherently intractable (but that is not unique to the Scotian Shelf). Temperate fish are not trout/salmon in streams, tropical reef fish, or even scallops. They move large distances over a wide range of habitat types. Associations between temperate fish and habitat type are hard to establish at meaningful scales. And this is just for abundance data, let alone rates or processes as impacted by habitat type. Given difficulties of applying Essential Fish Habitat (EFH) concepts in other parts of the world, the project should not proceed unaware

of these challenges. Certainly the work should proceed, but with careful consideration of how it is contextualized.

2. Relative importance of abiotic and biotic factors: doable with extant data but incomplete at this point. Some multivariate methods should be employed here.

3. Best methods to measure habitat: answer scale question first (below); the data nicely exist to address and the project is in a useful position to address this issue.

4. Spatial scales: for predicting habitat in a management context, likely bigger than the smallest but smaller than the biggest; needs to employ some among the many appropriate, possible statistical methods and it may be at multiple scales.

5. Where is preferred habitat: need to move away from this perspective and move towards thinking about a gradient of use.

FUTURE RECOMMENDATIONS

I would strongly recommend avoiding a copious string of concurrent and complex univariate statistics in subsequent analysis and presentations. Rather, I would strongly recommend exploring a suite of multi-variate statistics that are the preferred way to attempt to establish links among fish and habitat metrics.

To really grasp habitat utilization by fish, the project needs to nail down fish mobility. Similarly, the project needs to nail down scales at which to monitor fish and to map habitat.

Probably the biggest recommendation I can provide is to emphasize an analytical or synthesis phase for a period before initiating a new field program.

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APPENDIX A

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BIO – Bedford Institute of Oceanography
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EAC – Ecology Action Centre
Gadus – Private Company
Montreal – University of Montréal
NMFS – National Marine Fisheries Service
NRCan – Natural Resources Canada
SFRS – Scientists and Fisherman's Research Society
SFMGFA – Scotia Fundy Mobile Groundfish Association
SPANS – Seafood Producers of Nova Scotia
St. Mary's – Saint Mary's University, Halifax
Triton – Private Company
Ulster – University of Ulster, Belfast
URI – University of Rhode Island Graduate School of Oceanography
WWF – World Wildlife Fund

APPENDIX B

Meeting Agenda

SPATIAL UTILIZATION OF BENTHIC HABITATS BY DEMERSAL FISH ON THE SCOTIAN SHELF

SYNTHESIS MEETING

27 – 29 MARCH 2007

MAIN AUDITORIUM
BEDFORD INSTITUTE OF OCEANOGRAPHY
DARTMOUTH, NOVA SCOTIA

AGENDA

The purpose of this meeting is to present and review the results of a six-year research project conducted by a team of DFO and NRCan scientists from the Bedford Institute of Oceanography (BIO) and the Northwest Atlantic Fisheries Centre (NAFC) on the eastern Scotian Shelf (Emerald, Western and Sable Island Banks).

	TUESDAY MARCH 27, 2007
0900 h	**Introduction and Background**
	Welcome and Logistics – Don Gordon (BIO) & John Anderson (NAFC) (5 min)
	Project Overview – Don Gordon (BIO) (30 min)
	Trends in Temperate Marine Fish Habitat Research: Defining Habitat Based on Science and Legislation – Kent Gilkinson (NAFC) (30 min)
	Life Histories, Preferred Habitat and Stock Status of Haddock and Atlantic Cod – Bob Gregory (NAFC) (30 min) (presented by Jim Simon)
1035 h	Break
1100 h	Regional Geo-Science Setting of the Outer Scotian Shelf – Gordon Fader (BIO) (30 min)
	Data Management for Fish Habitat Studies – Pierre Clement (BIO) (30 min)
1200 h	**Lunch**
	Results – Session 1
1300 h	Fish Communities within the Scotian Shelf Habitat Study Area: Observations from Trawling – Edgar Dalley (NAFC) (45 min)
	Seabed Habitats as Revealed by Multibeam Surveys – Bob Courtney (BIO) (45 min)
1430 h	**Break**
1500 h	Seabed Habitat Properties as Determined from Sidescan Surveys – Gordon Fader (BIO) (45 min)
	Acoustic Surrogates for Demersal Fish Habitats on the Scotian Shelf: Haddock and Atlantic Cod – John Anderson (NAFC) (45 min)
	General Discussion – Don Gordon (BIO) & John Anderson (NAFC) (15 min)
1645 h	**Adjourn**

Wednesday March 28, 2007

0900 h **Results – Session 2**
Comparison of Abundance and Distribution of Juvenile Haddock and Cod Based on Trawl, Acoustic and Video Observations – John Anderson (NAFC) (45 min)

Fine Scale Habitat Associations of Juvenile Haddock on the Eastern Scotian Shelf – Bob Gregory (NAFC) (45 min) (**CANCELLED**)

1030 h **Break**

1100 h Scale Dependent Distributions of Haddock and Atlantic Cod within Preferred and Non-Preferred Habitats on the Scotian Shelf – John Anderson (NAFC) (45 min)

General Discussion – Don Gordon (BIO) & John Anderson (NAFC) (15 min)

1200 h **Lunch**

Results – Session 3

1300 h Juvenile Haddock and Cod: Dietary Links to Benthic Habitat – Ellen Kenchington (BIO) (60 min)

Epifaunal Communities on Western Bank – Kent Gilkinson (NAFC) (30 min)

1430 h **Break**

1500 h Habitat Suitability Indices for Juvenile Haddock and Atlantic Cod on the Scotian Shelf – Neil Ollerhead (NAFC) (30 min)

1530 h **Synthesis of Results**
New Insights into the Definition of Preferred and Non-Preferred Seabed Habitats for Demersal Fish – John Anderson (NAFC) (30 min)

Lessons Learned – Don Gordon (BIO) (15 min)

Future Plans – John Anderson (NAFC) (15 min)

1630 h **Adjourn**
Group Dinner at MacAskills

1900 h

Thursday March 29, 2007

0900 h **Review**
Introduction – Don Gordon (BIO) & John Anderson (NAFC) (15 min)

Critiques by External Reviewers
Daniel Boisclair, University of Montréal, Canada (15 min)
Craig Brown, University of Ulster, Northern Ireland (15 min)
Jeremy Collie, University of Rhode Island, USA (15 min)
Jason Link, National Marine Fisheries Service, USA (15 min)

1015 h **Break**

1100 h **General Discussion –** Chaired by Mike Sinclair (Director of Science, Maritimes Region)

1200 h **Concluding Remarks** Don Gordon (BIO) & John Anderson (NAFC)